DECEMBER 1951

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

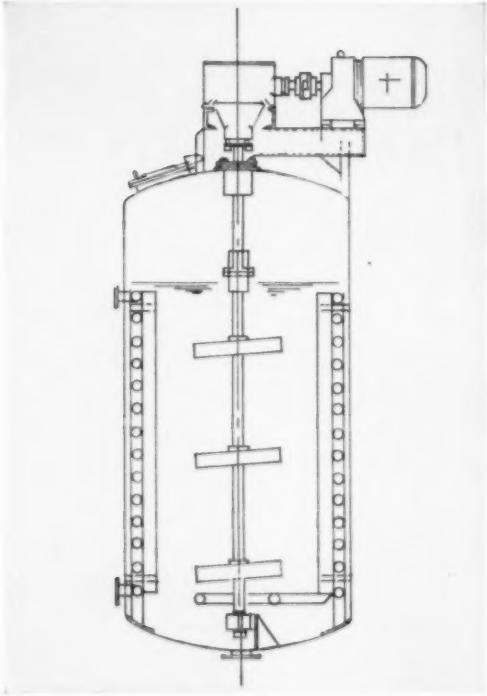
Turbo-Topics

TURBO-MIXER GENERAL AMERICAN

TURBO-MIXER, a division of

GENERAL AMERICAN TRANSPORTATION CORPORATION

300 h. p. Turbo-Mixers in operation!



Typical Turbo-Mixer Design for Anti-biotic Fermentation

After building more than 600 Turbo-Mixers for aerobic fermentation, the most powerful liquid mixers ever developed are now in action. These 300 h. p. mixers enable the manufacturer to handle his huge anti-biotic batch volume efficiently. *The high energy level required for maximum yield is still maintained!*

The entire 300 h.p. mixer was designed and supplied by Turbo-Mixer.

The success of these units—and the 200 h. p. Turbo-Mixers before them—rests upon custom design. Turbo-Mixers are always built for the specific job to be done. They work day-in and day-out with peak results.

Evidence of this efficiency and dependability can be found in the fact . . . that Turbo-Mixer has produced over 80% of the fermenters in the anti-biotic field throughout the world!

SALES OFFICE: 10 EAST 49th STREET, NEW YORK 17, NEW YORK

General Offices: 135 South La Salle Street, Chicago 90, Illinois • Offices in all principal cities

OTHER GENERAL AMERICAN EQUIPMENT:—DRYERS • EVAPORATORS • THICKENERS DEWATERERS • TOWERS • TANKS • BINS • FILTERS • PRESSURE VESSELS

Volume 47
Number 12

Chemical Engineering Progress

DECEMBER
1951

OPINION AND COMMENT

Page

STANDARDIZATION AND DIVERSITY
T. H. Chilton 593

ENGINEERING SECTION

SAFETY IN CHEMICAL PLANT OPERATIONS
Mathew M. Braidech 595

MANAGEMENT VIEWPOINTS ON PLANT SAFETY
Harold L. Miner 597

PERFORMANCE OF SPINNING DISK ATOMIZERS—PART II
C. R. Adler and W. R. Marshall, Jr. 601

AN EMPIRICAL EQUATION FOR THERMODYNAMIC PROPERTIES OF LIGHT HYDROCARBONS AND THEIR MIXTURES—Reduction of Equation to Charts for Prediction of Liquid-Vapor Equilibria
M. Benedict, G. B. Webb, L. C. Rubin, and Leo Friend 609

MASS-TRANSFER RATES ON BUBBLE PLATES—PART II. Results for Large Trays
J. A. Gerster, W. E. Bonnet, and Irwin Hess 621

DIFFUSION RATES IN THE EXTRACTION OF POROUS SOLIDS—PART II. Two-Phase Extractions.
E. L. Piret, R. A. Ebel, C. T. Kiang, and W. P. Armstrong 628

HEAT TRANSFER—Between a Vertical Tube and a Fluidized Air-Solid Mixture
W. M. Dow and Max Jakob 637

SOLVENT DRYING
R. J. Mitchell 649

CAST ALLOY REFERENCE SHEET (No. 6)
N. S. Mott 654

INDEX ..... I-V

NEWS

	Page		Page
NEWLY ELECTED INSTITUTE OFFICERS		A.I.Ch.E. CANDIDATES	46
A.I.Ch.E. AWARD WINNERS	17	SECRETARY'S REPORT	48
A POSTGRADUATION FIVE-YEAR PLAN FOR THE ENGINEER—*Ralph L. Wentworth*	18	LOCAL SECTION NEWS	50
INDUSTRIAL NEWS	20	LOCAL SECTION CALENDAR	50
MARGINAL NOTES	34	A.I.Ch.E. AND THE STUDENT CHAPTER—*L. P. Scoville*	52
DATA SERVICE INSERT	39-42	NEWS ABOUT PEOPLE	58
		CLASSIFIED SECTION	62
		NECROLOGY	64

MERRY CHRISTMAS AND HAPPY NEW YEAR TO ALL

Editor: F. J. Van Antwerpen ● **Publication Board:** T. H. Chilton, Chairman; W. I. Burt, Vice-Chairman; C. R. De Long, S. L. Tyler, W. L. McCabe ● **Publication Committee:** W. I. Burt, Chairman; W. C. Edmister, W. E. Lobo, R. H. Newton, J. H. Perry, M. C. Rogers, J. Skelly, F. J. Van Antwerpen ● **Advertising Manager,** Lansing T. Dupree.

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 120 East 41st Street, New York 17, N. Y. Communications should be sent to the Editor. Statements and opinions in *Chemical Engineering Progress* are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, $6.00; Canada, $6.50; Pan-American Union, $7.50; Other Foreign, $8.00. Single copies of *Chemical Engineering Progress* older than one year cost $1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1951 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulations. *Chemical Engineering Progress* is indexed regularly by Engineering Index, Incorporated.

PREDICTABLE PERFORMANCE FLOATS*

A Great New Advance in the Science of Flow Measurement

Now FLOWRATOR Meters can be

- Specified by Reference to Handbook Data
- Delivered Quickly from Stock
- Converted Easily, by the User, from one Service to Another

The performance of four basic F&P floats under varying conditions of temperature, gravity and viscosity is predetermined, has been accurately charted.

Complete data, published in Handbook form, enables users to determine their own meter requirements, to order meters from stocks now available, to convert any meter to any service within its capacity.

FOUR BASIC PREDICTABLE FLOATS MEET MOST REQUIREMENTS

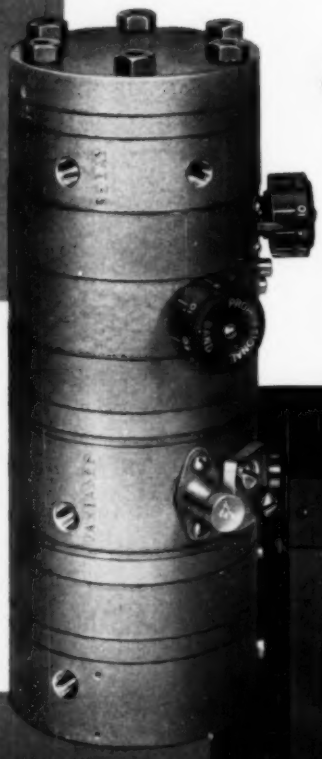
** The float is the basic metering element and the only moving part in the FLOWRATOR variable-area flow meter.*

WRITE FOR HANDBOOK

The F&P Variable-Area Meter Handbook contains a complete compilation of float lists, prediction curves, float data, selection instruction and much other information of value to all meter users. Your copy is free for the asking.

FISCHER & PORTER
COMPANY
HATBORO, PENNSYLVANIA, U.S.A.
SALES ENGINEERING OFFICES THROUGHOUT THE WORLD

Important

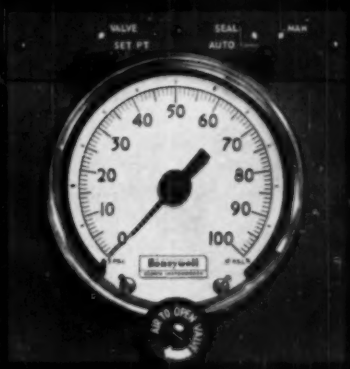


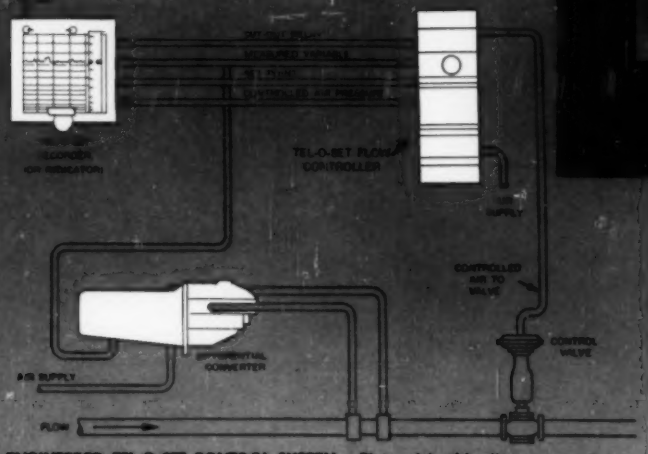
TEL-O-SET CONTROLLER

Available in adjustable and fixed proportional band models, and with three control forms . . . for flow, temperature, pressure, level and other process variables. Universal bracket permits optimum flexibility in mounting . . . coded, interchangeable sections and split manifold contribute to simplified maintenance. Write for Specification Sheet No. 768.

TEL-O-SET RECORDER

Features withdrawal of chassis for full 8-hour chart visibility without interrupting operations, bumpless shifting from automatic to manual operation, all adjustments from front of panel, built-in adjustable restrictions for pulsating flow . . . requires panel space just 5 1/16" high by 5" wide. Write for Specification Sheet No. 769.





TYPICAL ENGINEERED *TEL-O-SET* CONTROL SYSTEM—Pictured in this diagram are the elements of the *Tel-O-Set* Family, designed and built as an integrated loop. Here the system is applied to the control of flow with the *Differential* Converter used as transmitter.

TEL-O-SET INDICATOR

Can be used with any pneumatic transmitter, having a 3-15 psi controlled air output, regardless of the primary element being used. Provides indication of process variable, set-point of controller or controlled air pressure to valve when on automatic control . . . is easily shifted to manual operation. Panel cut-out size same as recorder. Write for Specification Sheet No. 770.

Contribution to Process Control

. . . THE HONEYWELL TEL-O-SET FAMILY

THIS pace-setting pneumatic control system is ready for application to a host of processes demanding a new high in speed, precision and accuracy . . . for almost any process variable. Developed as part of a family relationship, each unit complements the others in producing a system of superior performance.

Used with any one of a group of Honeywell measuring elements . . . for flow, temperature, pressure, liquid level, etc. . . . the *Tel-O-Set* system is destined to make important contributions to the improvement of process control throughout industry.

For more detailed information, send for the literature mentioned in the descriptions at left . . . or call in our local engineering representative for a discussion of your process control problems.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4427 Wayne Ave., Philadelphia 44, Pa.

MINNEAPOLIS **Honeywell**

Brown Instruments

H HONEYWELL

Uniformity

GLC Anodes for the electrolytic industry are uniform—they stand the test of comparison.

Baking Furnaces
Morganton
N. C. Plant

Plants:
Niagara Falls, N. Y.
Morganton, N. C.

Great Lakes Carbon Corporation

GLC

ELECTRODE DIVISION · NIAGARA FALLS, N. Y.

Sales Offices:
Niagara Falls, N. Y.
New York, N. Y.
Chicago, Ill.
Pittsburgh, Pa.

Representatives:
Birmingham, Ala.
Wilmington, Cal.

PRODUCTS OF GREAT LAKES CARBON CORPORATION

Electrode Division
Graphite anodes. Graphite and amorphous carbon electrodes. Carbon and graphite specialties.

Oil and Gas Division
Crude petroleum and natural gas.

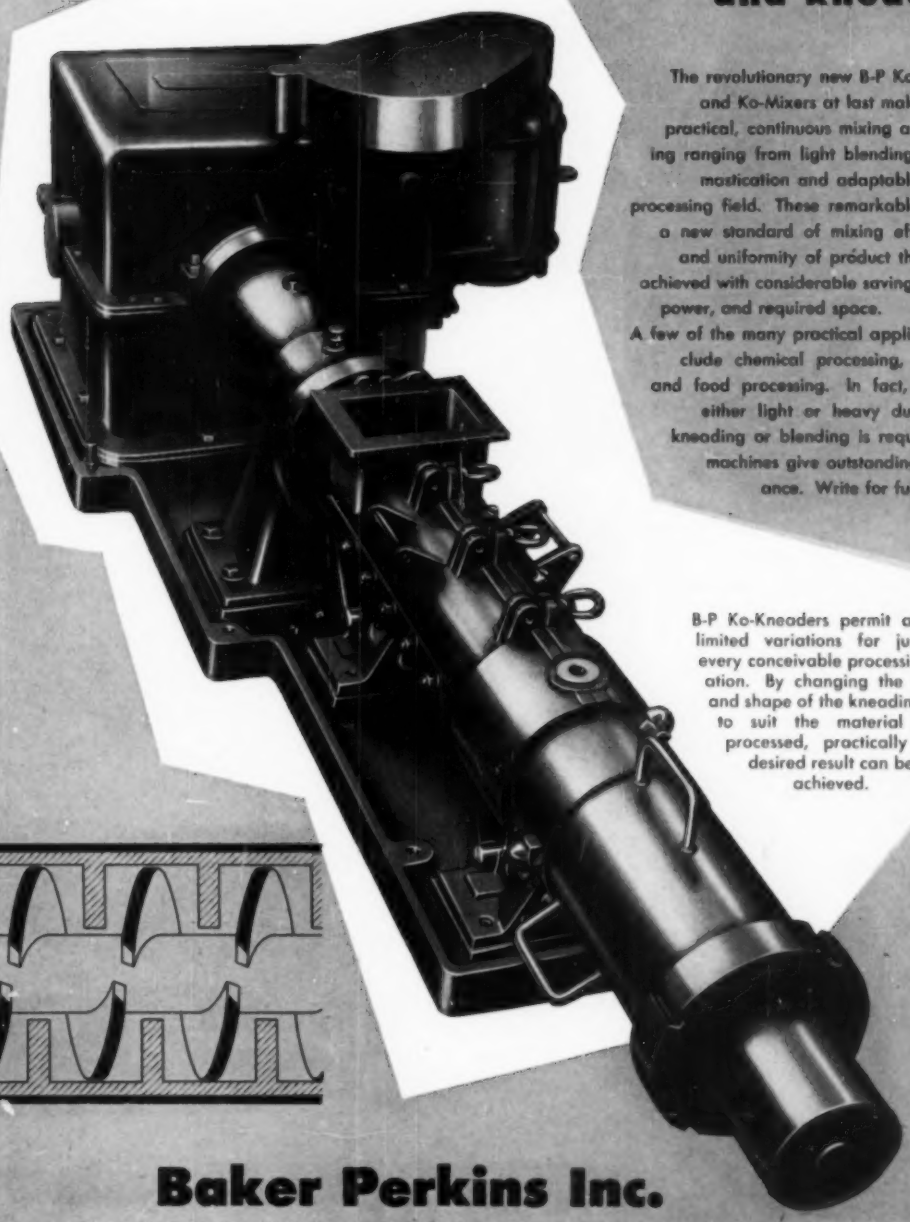
Carbon Division
Petroleum coke. Calcined petroleum coke. Industrial carbons.

Dicalite Division
Diatomaceous silica for filter-aids, fillers and insulating uses.

Perlite Division
Perlite lightweight aggregates and products for the building, oil, foundry and other industries. Perlite ore.

Merchant Coke Plant
Premium foundry and industrial coke. Coke co-products.

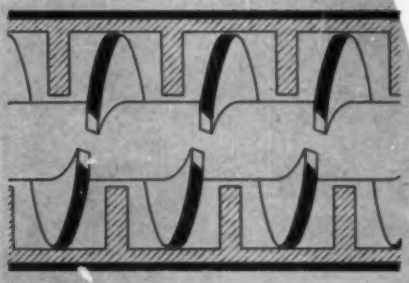
announcing! the new Baker Perkins "list system" ko-kneaders for continuous mixing and kneading



The revolutionary new B-P Ko-Kneaders and Ko-Mixers at last make possible practical, continuous mixing and kneading ranging from light blending to heavy mastication and adaptable to every processing field. These remarkable units set a new standard of mixing effectiveness and uniformity of product that can be achieved with considerable savings in labor, power, and required space.

A few of the many practical applications include chemical processing, foundries, and food processing. In fact, whenever either light or heavy duty mixing, kneading or blending is required these machines give outstanding performance. Write for further facts.

B-P Ko-Kneaders permit almost unlimited variations for just about every conceivable processing operation. By changing the number and shape of the kneading teeth to suit the material being processed, practically any desired result can be achieved.



Baker Perkins Inc.

Chemical Machinery Division, Saginaw, Michigan

ADVANCED CONSTRUCTION OF *Buflovak* EVAPORATORS GIVE

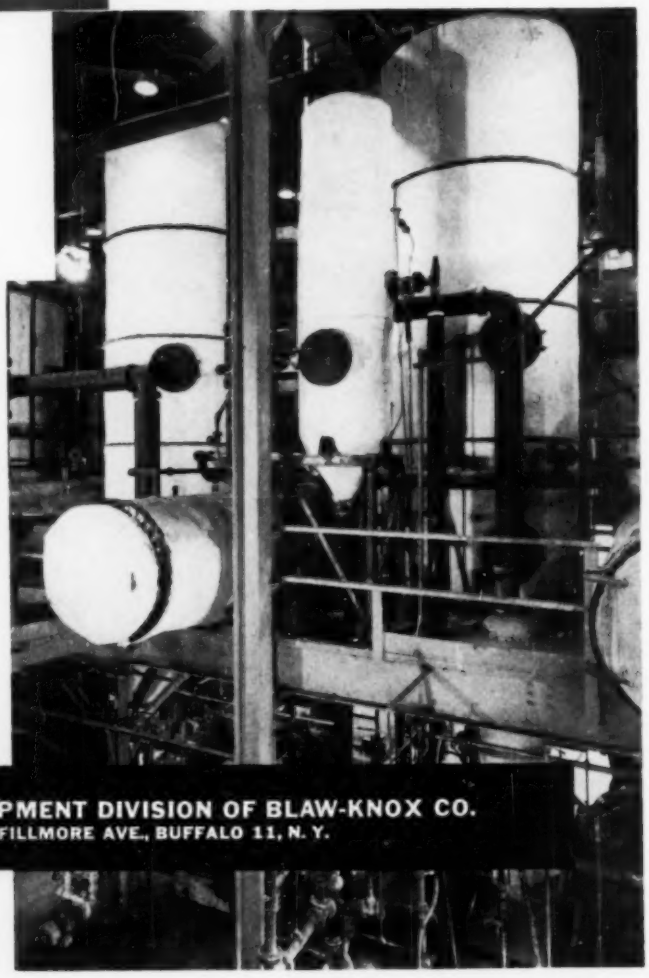
Buflovak Evaporators offer the chemical industry efficient evaporation of processing, high capacity and maximum recovery of solids. All of these because of advanced scientific design in every BUFLOVAK Evaporator!

Modern design insures maximum capacity, virtually complete recovery of all solids, and low operating costs. Automatic controls maintain a high level of operating efficiency, and simplify operation . . . all with their profit-building advantages.

✓ *HIGH RATE OF EVAPORATION*

✓ *MAXIMUM RECOVERY OF SOLIDS*

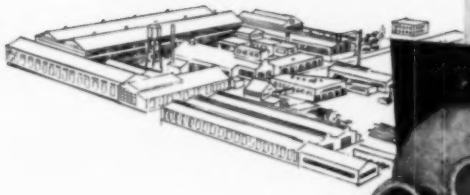
✓ *SIMPLIFIED OPERATION*

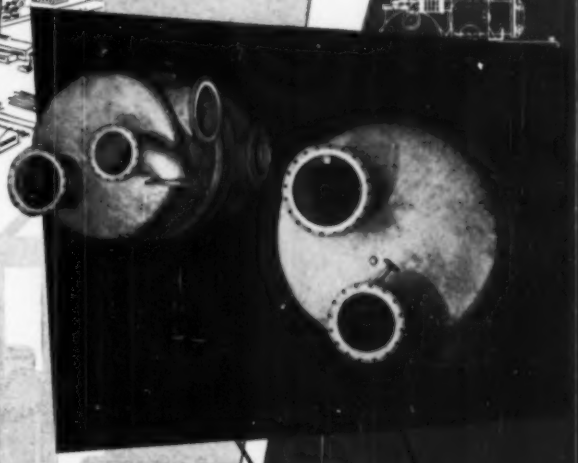


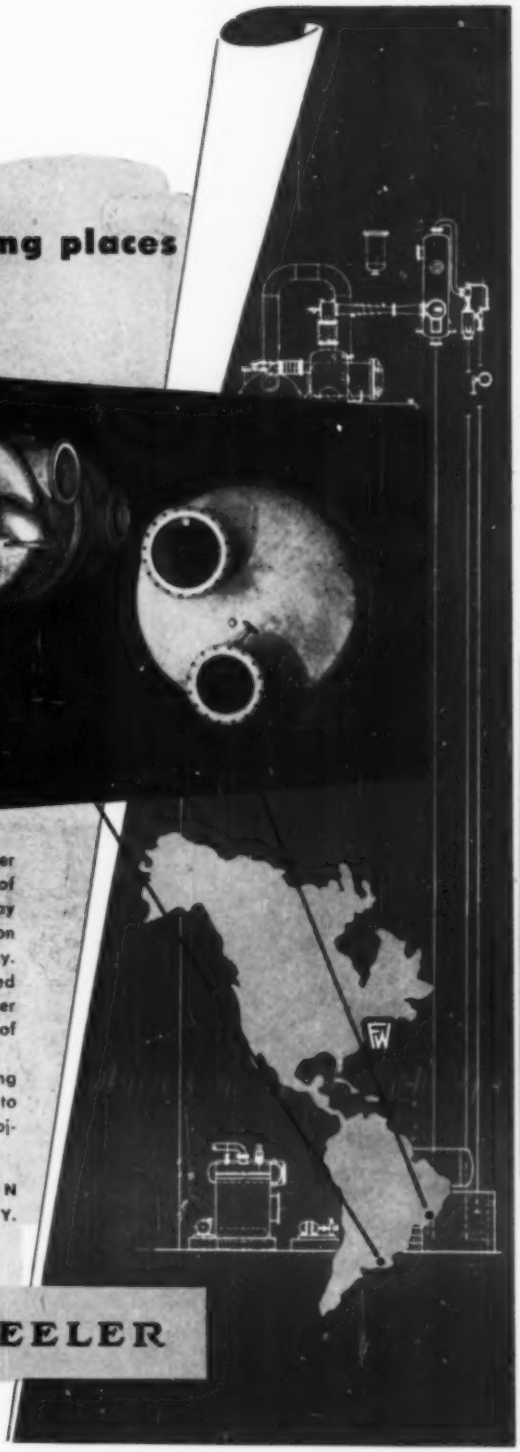
BUFLOVAK Triple Effect, Forced Circulation Evaporator with built-in Salt Separators. Used to concentrate caustic and to recover salt crystals from the process. This unit produces 90 tons of 100% NaOH in a 50% solution from cell liquor. Horizontal heating elements afford complete tube accessibility. The tubes are always completely filled with liquor. Flashing cannot occur. Unit is built of nickel and nickel clad steel.

BUFLOVAK EQUIPMENT DIVISION OF BLAW-KNOX CO.
1567 FILLMORE AVE., BUFFALO 11, N. Y.

the design that's going places







FATTY ACID DISTILLATION

These stills have been fabricated along with other process components at the Carteret, N. J. shops of Foster Wheeler for export to Montevideo, Uruguay and Santos, Brazil where plants for the distillation of fatty acids are being erected by the company.

Both plants are based on a design which proved highly effective in connection with other Foster Wheeler installations now producing upwards of 150,000,000 pounds of fatty acids per year.

Foster Wheeler, with its complete engineering and construction services, is uniquely equipped to provide the overall responsibility for far-flung projects of this nature.

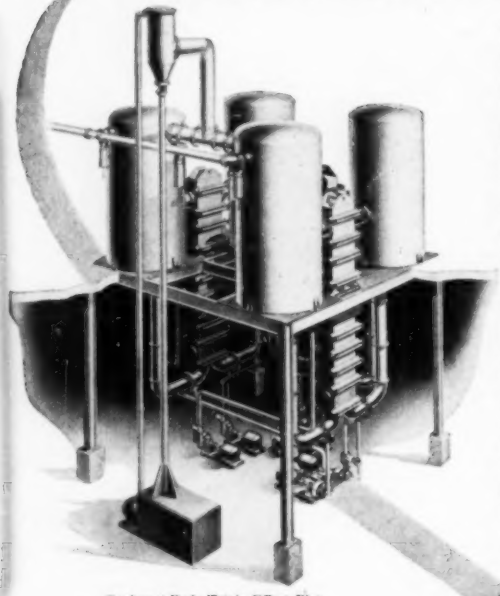
FOSTER WHEELER CORPORATION
165 BROADWAY, NEW YORK 6, N. Y.

FOSTER WHEELER

Conkey Flat Plate Evaporators with Rosenblad Switching System*

Completely self-cleaning during operation

No down time! No scale removal costs!



Conkey 4-Body Triple Effect Flat Plate Heating Surface Evaporator

Take a leaf from the flow sheets of another industry. For years evaporation of spent sulphite pulp cooking liquors in sulphite pulp manufacture was considered highly impractical because a gypsum coating developed on heating surfaces. But today—it can be a *continuous, full capacity self-cleaning operation* through use of Conkey Evaporators and Rosenblad Channel Switching System.

The advantages of the Rosenblad Channel Switching System have been thoroughly proven both in this country and abroad. Heating surfaces, interconnecting pipe and pump systems *are completely cleaned during normal operation!* It's especially effective wherever lime salts scale evaporators.

Conkey equipment adapts itself well to channel switching for self-cleaning operation while providing all the other advantages of multiple effect evaporation: forced circulation . . . falling film . . . recompression . . . thermal compression . . . high vacuum and other specialized benefits where required.

*Patents Applied For

PROCESS EQUIPMENT DIVISION
GENERAL AMERICAN
TRANSPORTATION CORPORATION

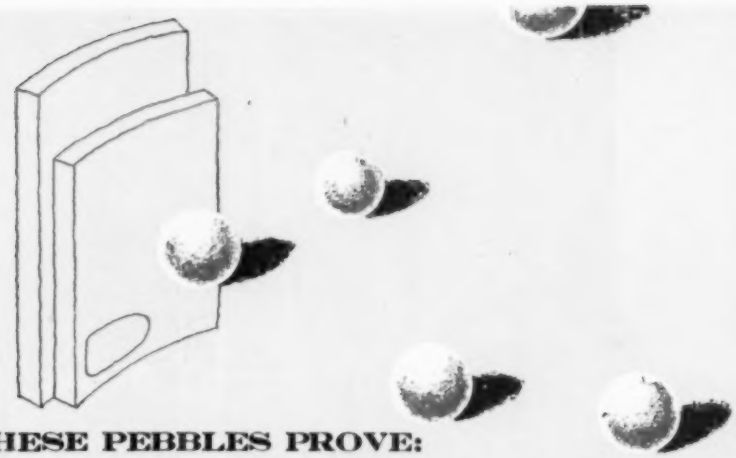
Sales Offices: 10 East 49th Street, New York 17, New York
General Offices: 135 South LaSalle Street, Chicago 90, Illinois

Sole licensee in the U. S. A. for the
A. B. Rosenblads Patenter Evaporator Switching System.
OFFICES IN ALL PRINCIPAL CITIES

PROCESS EQUIPMENT DIVISION GENERAL AMERICAN TRADE MARK

GET THE FULL DETAILS. Write today for new bulletin. See how a Conkey Evaporator with Rosenblad Switching System can eliminate down time, eliminate scale removal costs and keep a constant flow sheet for you.

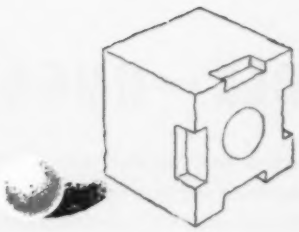
Other General American Equipment: Turbo-Mixers, Filters, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels.



THESE PEBBLES PROVE:

IN REFRACTORIES

ALCOA ALUMINA CAN TAKE IT

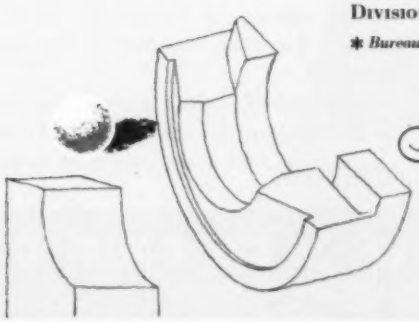


In a recent 7-month test conducted by the Bureau of Mines*, ALCOA Alumina proved it can stand up under grueling treatment. During this period, ALCOA Tabular Alumina pebbles passed through a commercial-size pebble heat exchanger. During each cycle they were alternately heated to above 2000° F. and cooled to 300°-450° F. Yet under these extreme operating conditions, the ALCOA pebbles gave excellent service and considerably out-performed other pebbles tested. They showed unusually low breakage from heat and mechanical shock as well as outstanding resistance to abrasion. These same excellent results are being attained with ALCOA Alumina pebbles in other commercial pebble heat exchangers.

Aluminum oxides in various forms are widely and successfully used for super-duty refractories . . . special cements . . . grinding balls . . . spark-plug insulators . . . and a variety of ceramic bodies. If severe operating conditions are causing you refractory problems, perhaps you can benefit from the exceptional performance record of ALCOA Aluminas. Let us show you how they can profitably apply to *your* business.

Write to: ALUMINUM COMPANY OF AMERICA, CHEMICALS DIVISION, 605M Gulf Building, Pittsburgh 19, Pennsylvania.

* *Bureau of Mines, Report of Investigations 4781*

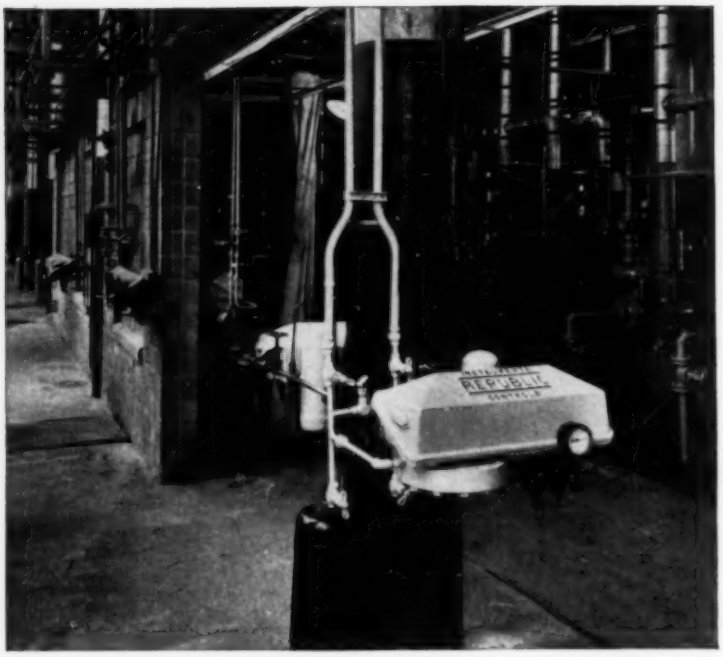


Alcoa Chemicals

ALCOA

ALUMINAS and FLUORIDES

ACTIVATED ALUMINAS • CALCINED ALUMINAS • HYDRATED ALUMINAS • TABULAR ALUMINAS • LOW SODA ALUMINAS ALUMINUM FLUORIDE • SODIUM FLUORIDE • SODIUM ACID FLUORIDE • FLUOBORIC ACID • CRYOLITE • GALLIUM



These Meters Had To Be
ACCURATE — FLEXIBLE — RUGGED

One hundred twenty one Republic Pneumatic Transmitters are measuring the flow and level of various acids in a large chemical processing plant, a section of which is pictured above.

These transmitters have a guaranteed accuracy of within ½ of 1% of the transmitter range. By making a few minor adjustments or substituting a few small parts, their operation can be easily changed to any desired range between a minimum of 0—0.6" of water to a maximum of 0—704" of water. Their construction is more like that of a precision machine than of the sensitive instrument they are. It is for these reasons that Republic Pneumatic Transmitters, even though comparatively new, have already been specified and installed on over 2500 industrial metering applications.

Republic Pnuematic Transmitters are available for measuring flow, liquid level, pressure or liquid density of a wide range of fluids. They employ the force-balance principle to convert these process variables into air pressures which vary proportionally. These air pressures become direct measurements and can be conducted to reading instruments or used as the measuring impulse for the actuation of an automatic controller.

Data Book No. 1001 contains complete details on the construction and operation of Republic Transmitters. Write for your copy today.

REPUBLIC FLOW METERS CO.
2240 Diversey Parkway, Chicago 47, Illinois

★ For Direct Heating of Liquids and Vapors

★ Indirect Heating Systems Using Circulating Medium

Struthers Wells

FIRED HEATERS

for the Process Industries

A complete line of direct fired heaters is available in standard sizes from 100,000 to 25,000,000 BTU per hour. These units are in wide use in services such as heating gasoline, oils or asphalts, superheating steam or gas, and for indirect heating systems. The heaters are shipped shop assembled except for the largest sizes.

Struthers Wells indirect heating systems, utilizing either a vapor or liquid heat transfer medium, such as Dowtherm, are giving economical and trouble free operation at temperatures to 750° F., or above this.

Equipment is ordinarily supplied with instruments and safety controls to give a complete installation. Large installations in service for many years testify to the correct design and quality of this equipment.

If your process requires temperatures above those of existing steam supply, if steam is not readily available, or if the process can be improved by higher temperatures, this economical and simple equipment will be of interest. We can also supply smaller equipment, electrically heated, as package units.

Write on your letterhead for our new Bulletin B-45, describing a complete line of equipment for high temperature process heating.

Struthers Wells

STRUTHERS WELLS CORPORATION

Warren, Pa.

PLANTS AT WARREN, PA. • TITUSVILLE, PA.

Offices in Principal Cities

recovered oil pays for Cyclator® Operation

AT THIS OHIO MANUFACTURING PLANT

Effluent Sparkles in Golf Course Stream

THIS large Ohio manufacturing plant had over 100,000 g.p.d. of waste liquids, including pickling acids, chrome plating residues, cutting oils and alkaline cleaner solutions. With the Cyclator and a primary clarifier the effluent is so clean it furnishes the main flow for a nearby golf course stream! Chemical cost of $12.00 per day, the salary of a part-time operator and other running expenses are more than paid for by recovered oil.

Here's an Amazing Waste Reduction Story:

Soluble and insoluble oil from 2950 to 15 p.p.m.
Chromium reduced to .1 p.p.m.
BOD of alkaline waste from 2000 to 30 p.p.m.

INFILCO
BETTER WATER CONDITIONING AND WASTE TREATMENT SINCE 1934

INFILCO INCORPORATED | *Tucson, Arizona*

FIELD ENGINEERING OFFICES IN 26 PRINCIPAL CITIES

World's Leading Manufacturers of Water Conditioning and Waste-Treating Equipment

Let's take a CLOSER LOOK at STRAIGHT-CHROMIUM Stainless Steel Tubing

Present restrictions on nickel have cut production of austenitic stainless steel tubing far below demand. If this critical shortage of nickel-bearing stainless tubing is compelling you to find other suitable grades, you should take a closer look at the straight-chromium analyses.

Readily available in quantity from B&W are pipe and tubes of the four non-nickel-bearing types listed at the right with typical uses. These ferritic and martensitic steels are magnetic at ordinary temperatures after all conditions of heat treatment, have relatively high oxidation resistance at elevated temperatures, and resist attack by many corrosive media. With certain modifications in procedures, they can be satisfactorily fabricated by all methods applicable to austenitic grades.

For both pressure and mechanical applications, tubes of straight-chromium stainless analyses are worthy alternates for hard-to-get nickel-bearing stainless types. Would you like a copy of TDC-140 containing technical data on these easy-to-get grades of stainless tubes? Ask Mr. Tubes—your B&W Tube Representative—about their suitability for your applications.

APPLICATIONS

B&W Croloy 12 A1 (Type 405, Seamless)—Non-hardening—does not undergo appreciable transformation; therefore no sudden volume change occurs during heating—corrosion and oxidation resistant. Typical uses: Conveyor lines in oil refining and chemical processing, heat exchanger tubing, boiler tubing in mercury heat cycle, catalytic oil cracking processes where fins have been welded to tubes.

B&W Croloy 12 (Type 410, Seamless and Welded)—Hardenable—moderate corrosion and heat resistance. Typical uses: Machinery in the chemical and food processing and packaging fields.

B&W Croloy 18 (Type 430, Seamless and Welded)—Sufficient ductility for forming simple parts—good corrosion and oxidation resistance—can be polished or buffed to pleasing finish. Typical uses: Conveyor lines in chemical processing field; condensers and piping in production, transportation, and storage of nitric acid and in nitrating operations involving mixed acids; furnace parts; retorts; ornamental structures.

B&W Croloy 27 (Type 446, Seamless)—Corrosion resistant—excellent heat resisting qualities. Typical uses: Furnace parts, heat interchangers, kilns, pyrometer protection tubes, soot blower elements, dehydrogenation equipment in chemical and oil refining fields. Also well suited for glass sealing applications.

THE BABCOCK & WILCOX TUBE COMPANY

Executive Offices: Beaver Falls, Pa.

General Offices & Plants

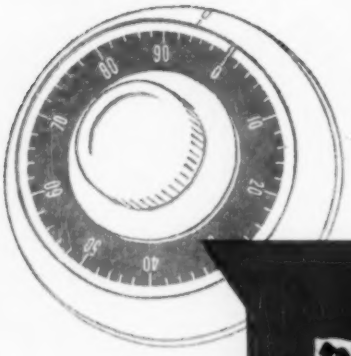
Beaver Falls, Pa.—Seamless Tubing; Welded Stainless Steel Tubing
Alliance, Ohio—Welded Carbon Steel Tubing

Sales Offices: Beaver Falls, Pa. • Boston 16, Mass. • Chicago 3, Ill. Cleveland 14, Ohio • Denver 1, Colo. • Detroit 26, Mich. • Houston 2, Texas • Los Angeles 17, Calif. • New York 16, N. Y. • Philadelphia 2, Pa. • St. Louis 1, Mo. • San Francisco 3, Calif. • Syracuse 2, N. Y. Toronto, Ontario • Tulsa 3, Okla.

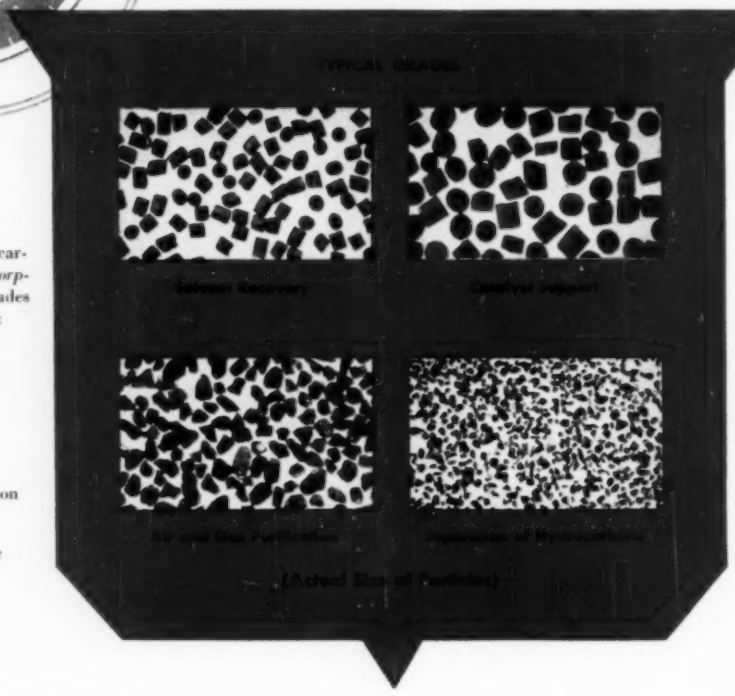
B&W STAINLESS and WELDED TUBES

TA-16515

For the RIGHT COMBINATION of Properties



use COLUMBIA
TRADE-MARK
ACTIVATED CARBON

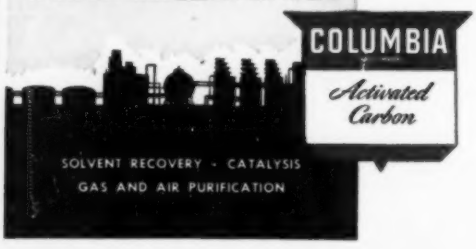


We supply special activated carbons for all *gas* and *vapor adsorption* applications. Several grades are produced specifically for:

- Solvent Recovery
- Air Deodorization and Purification
- Industrial and Military Gas Masks
- Purification of Industrial Gases
- Separation and Purification of Hydrocarbon Gases (moving beds)
- Catalysis of Vapor-Phase Reactions

CARBIDE AND CARBON CHEMICALS COMPANY

A Division of
Union Carbide and Carbon Corporation
30 East 42nd Street UCC New York 17, N. Y.



There is no *one* activated carbon for *all* uses. Optimum characteristics vary with each application. The *right combination* of properties is required in an adsorbent for most effective results. And there is a COLUMBIA Activated Carbon with the combination you need.

Let us help you select the proper COLUMBIA Activated Carbon for your particular job—the grade that combines the best particle size and shape, active surface area, adsorptive and catalytic properties, ash content, hardness, and mechanical strength.

Write today, describing your application, and our engineers will give you further detailed information.

"Columbia" is a registered trade-mark of Union Carbide and Carbon Corporation.

OPINION AND COMMENT

STANDARDIZATION AND DIVERSITY

IT IS hard to realize that as little as 25 years ago some cities and even states used other colors for traffic signals than green, yellow, and red for Go, Caution, and Stop. The necessities of the situation—and the efforts of the standardizing bodies—have brought about nearly complete uniformity of usage in traffic lights. (Those of us who are blessed with normal vision still hear occasional complaints from the color-blind that the positions in which the lights are arranged, more significant to them than the spectral transmission, are not yet reliably standardized. Maybe this will come in time.)

What needs to be standardized? What should be left free to flourish in diversity? The same illustration will serve for an answer. The traffic signals, obviously, must be standardized, while advertising signs can compete for your attention each in a different hue as you drive along the highway. Utilitarian purposes are aided by standardization; aesthetic, by diversity.

Engineering is concerned principally with utilitarian objectives. Most of the things with which the engineer has to deal must be subject to standardization. The basic things call for authoritarian or government action: standard time, length of the inch, the weight of the pound. But agreement of those concerned is sufficient for many others: wire and sheet metal gages, screw threads, hose couplings. The engineering societies offer a means to achieve agreement in the fields of their interests. But interests are not easy to confine, and often overlap with those of other engineering groups and of trade associations. Recognition of this fact led five engineering societies to establish in 1918 the American Standards Association as a national clearinghouse for standards activities. The procedures worked out for its operation provide machinery for ascertaining what subjects should be brought under standardization, and what groups have a legitimate interest in these subjects; for reaching a consensus of these groups; for designating the result of such agreement as an American Standard upon being satisfied that such a consensus has been reached; and for revision of such standards at sufficient intervals to assure their being in step with advances in technology.

The A.I.Ch.E. was not one of the five societies that founded the A.S.A. It is a matter of satisfaction to your present officers, though, that beginning with 1950, the Institute is now a full member-body of the Association, with a representative on the Standards Council.

In addition to that representation on the governing body for standardization procedure, the A.I.Ch.E. is officially represented on several of the A.S.A. technical committees, through which the work of the Association is actually carried on. These have for some time included the following: Safety code for mechanical refrigeration, Safety code for dry cleaning units, Allowable concentration of toxic dusts and gases, Standard code for pressure piping, Graphical symbols and abbreviations for use on drawings, and Letter symbols and abbreviations for science and engineering. The A.I.Ch.E. committee on Symbols and Nomenclature serves as the chemical engineering subcommittee of the last-named committee.

Upon the formation by the A.S.A. in 1950 of the Chemical Industry Correlating Committee, at the request of the Manufacturing Chemists' Association, the Institute responded by designating a representative, and alternate, on this committee, along with the A.S.T.M., the A.S.M.E., the A.P.I., the S.O.C.M.A., and, of course, the M.C.A. The activities of this committee are limited to needed standardization of procurement items—the things the industry buys—and thereby exclude product standardization. It has established four subcommittees, and the first of these, dealing with stainless steel pipe and fittings, has secured the adoption of a new schedule covering thin-walled stainless pipe and welding fittings. A second is working on greater uniformity in stainless steel analyses, in collaboration with the A.S.T.M. A third is concerned with valves and fittings for hazardous gases and liquids. The efforts of Subcommittee No. 4 are directed toward presenting suggestions for modifying and amplifying the A.S.M.E. Code for Unfired Pressure Vessels so as to make the use of the Code less onerous and more acceptable to the chemical industry. Other subcommittees are in course of formation.

In addition to these official representatives, there are many individual members of the Institute who serve on A.S.A. committees, or as representatives of their employers in the conference of company members—industrial concerns who contribute most of the financial support for the operation of the Association.

The Institute carries on within its own confines activities appropriate to its own sphere. Its committee on Symbols and Nomenclature has been endeavoring to promote agreement on letter symbols and abbreviations that will enhance the intelligibility of chemical engineering literature—taking due regard to usage in other fields. It was the product of this committee that was adopted as an American Standard, ASA Z10.12-1946. It is now engaged in revising and enlarging this list, and is undertaking to provide a set of graphical symbols for conventional representation of process equipment units.

Along a slightly different line, the Committee on Testing Techniques is setting out to secure agreement on standardized procedures for testing the performance of process equipment. It has ready for publication a procedure on shell-and-tube heat exchangers.

These are some of the ways in which the Institute is trying to serve the chemical engineering profession and the chemical and process industries, acting for itself where its interests do not overlap with others', and in collaboration with others in appropriate joint councils and associations. I commend these activities to the wholehearted support of the membership.

Thomas H. Chilton, President, A.I.Ch.E.

TYGON

Versus H_2SO_4

ONE good answer to many sulfuric acid corrosion problems is the versatile TYGON family of plastic compounds. Consisting of carefully compounded polyvinyl resins, TYGON — as a material of construction, as a medium of transmission, and as a protective coating — exhibits outstanding resistance to sulfuric acid over a wide range of concentrations and conditions.

TYGON is available in molded, calendered and extruded form, as a plastisol and as a solvent type paint. Each form is specifically suited for certain applications. Each has its limitations. All have the basic characteristics of vinyl based materials. All are backed by the "know-how" of almost 87 years experience in corrosion control.

As a material of construction, TYGON is used primarily in sheet or molded form, although extruded tape, channel, or solid cord is sometimes used. In 3/32" thick sheets TYGON is used to line tanks, drums, and hoppers; to protect fume hoods and ducts; to cover work tables and floor areas. TYGON sheets are also cut into gaskets for positive, enduring seals in all types of process equipment. TYGON sheet resists sulfuric acid, its fumes and salts, for long periods in concentrations up to 42°-55° Bé acid, or equivalent, depending upon the compound used. Service temperature limit ranges from 150° to 175°F. Molded TYGON sees service as grommets, washers, gaskets, stoppers, handles, bumpers and special fittings. In these forms, TYGON resists up to 55° Bé acid at temperatures ranging up to 200°F. With either sheet or molded TYGON, prolonged contact with fuming sulfuric acid, sulfuric anhydride, and mixed acids is not recommended without the counsel of U. S. Stoneware engineers.

As a piping medium, TYGON is most generally used in the form of extruded tubing. However, some short flexible couplings and other special fittings may be molded, or cast from plastisols. Lightweight, flexible TYGON Tubing, in sizes up to 2" ID, is used as temporary or permanent transfer lines, as flexible connections, as inlet and discharge ports on acid pumps, as gas lines, or as syphon hoses. TYGON Tubing resists up to 55° Bé sulfuric acid at temperatures as high as 200°F. Specific temperature limits vary according to the compound used, the pressures involved and the wall thickness of the tubing. Where constant pressures of more than 40 psi are involved, braided jacket reinforcement is available and should be used. Prolonged use with fuming sulfuric acid, sulfuric anhydride, and mixed acids is not recommended without consultation.

As a paint, TYGON affords excellent protection to tanks, equipment, structural steel, walls and ceilings, against the fumes or spillage of sulfuric acid in any concentration. Temperature limit is approximately 200°F. The limitations of a thin film should be realized and contact, other than brief or intermittent, with concentrated acid, moist sulfur trioxide, and mixed acids should be avoided. For mild environments a primer and no less than two top coats should be used. For severe exposures a minimum of five coats plus primer is advised.

For a heavier duty coating, TYGON as a plastisol (TYGOFLEX) can be applied by dipping and fusing, or by spraying. TYGOFLEX is particularly suited to the application of a thick coating on intricate shapes, with or without adhesion.

In any of its forms, TYGON provides low cost protection and high degree of safety in the handling of not only sulfuric acid and related chemicals, but a wide range of other acids, alkalies, oil, greases and water. The number of forms available and the flexibility possible in mechanical, physical and chemical properties of the standard compounds permit its proper use in many applications. The versatility of TYGON is further increased by the availability of custom compounding and molding. For the best results with TYGON, consultation with U. S. Stoneware engineers is strongly urged.

TYGON plastics

In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling sulfuric acid in any concentration and under all types of operating conditions. These products include chemical stoneware and porcelain, acid proof brick and cements, homogenous lead linings, and other organic linings and coatings.

Why don't you submit your corrosion problem, today? There's no obligation and we'll be pleased to be of assistance. So write, now!

THE UNITED STATES STONEWARE CO., Akron 9, Ohio

ENGINEERS, MANUFACTURERS, ERECTORS OF CORROSION-RESISTANT EQUIPMENT SINCE 1865

Safety

IN CHEMICAL PLANT OPERATIONS

MATHEW M. BRAIDECH

National Board of Fire Underwriters, New York, N. Y.

"Safeguarding What You Have" is the general theme under which the articles below are presented. In these days of shortages of materials, manpower, and equipment, it is the responsibility of executives and engineers to conserve and preserve plant assets.

The first of this series is on Safety. Plans call for it to be followed by articles on maintenance, corrosion, and manpower.

Safeguarding what you have is important. Each fire, each accident slows our production facilities, and if management can install safety programs and measures which will prevent an accident, the results are all to the good.

Here below, Mathew Braidech, research director, National Board of Fire Underwriters, presents some of the dramatic implications in safety and the prevention of accidents. This is followed by an article by Harold L. Miner, formerly manager plant protection and safety division, Du Pont Co., Inc., Wilmington, Del. His theme, pointed and direct, pulls no punches; management is responsible for safety. If management wishes maximum protection, management must have maximum safety thinking.

OUR complex industrialized civilization with its accelerated processings and mass production has brought us both blessings and bane—it has provided us the enjoyment of a high scale of living, and a thorny record of serious life loss and severe property damage.

Latest figures of human and economic loss tell us that our 1949 accidents cost us around $7,500,000,000 (or about one fifth of our present annual national defense budget). Everyone should share the responsibility and duty to help eliminate accidents which annually kill some 91,000 fellow Americans, and injure 10,000,000 citizens, with a loss of 275,000,000 man-days. These cold figures should make us realize that industrial safety is a national problem of first magnitude.

Safety can be said to be everybody's business, but, it has been said, what is everyone's business can sometimes be nobody's responsibility. Industrial safety, however, is an area of engineering interest, since engineering in its final analysis consists of utilization of materials, machinery, and men in an efficient combination to accomplish a specific economic objective. Engineering certainly implies the exercise of sound judgment and proper application of scientific and technical knowledge to avoid wastage of our natural, created, and human resources. That our moral responsibility in this regard is inescapable is indicated rather clearly in the Canons of Ethics of the Engineers' Council on Professional Development, which states the following:

> The engineer will have due regard for the safety of life and health of the public and employees who may be affected by the work for which he is responsible.
>
> He will guard against conditions that are dangerous and threatening to life, limb or property on work for which he is responsible, or if he is not responsible, he will promptly call such conditions to the attention of those who are responsible.

It can be seen that it is impossible to separate safety and accident prevention from our daily activity as engineers. Furthermore, management is beginning to realize that safety and accident prevention are also closely related to operating efficiency and that in the long run it is good business. The impact of our current national defense program will cause us to realize this fully, as we approach capacity use of manpower, material, and machines.

The value of safety is reflected in a long-range study of the past record. The accident death rate in the United States in 1907 (when authentic figures were first available) was 93.7 per 100,000 population, the highest death

Fire protection technicians testing fire extinguishers. Below a 10-lb. carbon dioxide extinguisher used with a sweeping motion drives the fire from the cotton waste.

Courtesy National Board of Fire Underwriters

Courtesy National Board of Fire Underwriters

Testing fire doors for endurance against both fire and hose stream action. These closures are intended to provide safeguarding protection for openings in walls and partitions against passage of fire, heat and smoke.

rate in U. S. history. This was reduced to 85 in 1913, when safety was first recognized on a formal basis, and eventually to the present rate of about 60 per 100,000—meaning a saving of nearly 430,000 lives through organized accident prevention. It must be pointed out also that these decreases took place in the face of a huge industrial expansion.

The foregoing reductions have also been accompanied by parallel decreases in loss and proportionate conservation of properties and materials. These results have not simply drifted on the sea of chance. Guiding safety signposts have been formulated over the span of years by reasons of necessity and as a matter of good business through the activities of some 160 trade associations, industrial groups, technical societies and governmental agencies—50 of whom have sponsored some 1000 committees concerned with standardization and furtherance of safeguards. As a result, American industry, in general, is today replete with regulations and safety codes through which safety engineers, governmental factory inspectors, insurance engineers and industrial consultants play an important role in safety control. The A.I.Ch.E. has made valuable contributions from time to time in this regard.

While the chemical industry has been breaking production records, its safety record has been most outstanding. The 1950 Accident Facts of the National Safety Council informs us that the 1949 injury frequency rate (number of disabling injuries per million manhours) for the chemical industry was 5.72, compared to the all-industry value of 10.14, placing the chemical group 7th on the list of some 40 industries. Petroleum with 10.54 was 21st, foundries with 14 were 28th, food with 16 was 30th, construction, mining and lumbering with 20, 35, and 48, respectively, placed at the bottom as most hazardous. In terms of the injury severity rate (days lost per 1000 manhours), the chemical industry rated 14th with a value of 0.60 (all-industry value: 1.02), and, in comparison with the foundry, construction, lumbering and mining, the values were 1.47 (27th), 2.15, 4.67 (35th), and 6.84 (41st), respectively. The frequency and severity rates for the chemical industry were reduced in half in the last five years, truly, a great record and a credit to our profession.

Looking beyond the present-day, our technology is growing and expanding in upside-down pyramid fashion and we may soon be faced with increased burdens and greater responsibilities as far as safety is concerned. We are lagging behind in our reservoir of engineers. A recent report made to the American Society of Engineering Education by Dr. John Nielsen informs us that even though the number of engineers has grown six times as fast as our population, since 1870, a most serious shortage of engineers may occur by 1970. The following growth figures are informative:

Year	Number of Engineers
1870	7,000
1910	85,000
1950	350,000
1970	660,000

In the entire field of engineering there are as many as 2000 fields of specialization subordinate to the older recognized fields. Chemical engineering alone has some 300 cells of specialization. In view of the foregoing one can appreciate the doubling of responsibility for engineered safety and safety engineering if we are to continue our fine safety record.

While we experience in this country some 700,000 fires and explosions a year, insurance records show that one third of 1% of our fires are responsible for 60-70% of our losses, which total in a loss excess of one-half billion dollars. Most of this damage resulted in our industrial areas of high-value concentrations. The fire and explosion loss potential can be quite severe for several of our chemical plants, and this item of safety should be of special interest to all designing and supervising chemical engineers.

The unusually low fire record of one of our larger synthetic organic chemical establishments, involving many hazardous and extra-hazardous processes should be cited. It is interesting to report that over the past five-year period this organization experienced a 25% decrease in fire and a 90% decrease in losses—this was accomplished in the face of a 30% expansion. Its fire protection and safety department conducts some 45,000 routine inspections and tests, involving nearly 90,000 manhours of engineering service. Its annual program includes scheduling some 10,000 piping tests, 4,000 equipment tests, along with the testing and servicing of some 11,000 safety valves, 14,000 pressure gauges, and 4,000 routine examinations and checks of flame arrestors, flammable vapor indicators, and various process control equipment. This is truly an important adjunct to production.

Safety is primarily a matter of cooperative care, sensible caution, good housekeeping and proper maintenance—beginning with design and ending with operation. In the final analysis safety calls for a three-way responsibility—good management, capable engineering supervision, and the correct workman attitude.

Mathew M. Braidech, research director, Fire Prevention and Engineering Standards Department of National Board of Fire Underwriters, New York, is a graduate of Ohio State University in chemical engineering with a B.Ch.E. (1925) and Ch.E. (1931). From 1936-45 he was professor of industrial chemistry, Case Institute of Technology, Cleveland, and prior to that for ten years was chief chemist, Department of Public Utilities, City of Cleveland. He has been a special investigator in many fire and explosion disasters. More recently Mr. Braidech has been a member of the research committee of the President's Conference on Industrial Safety and a consultant to the National Commission on Safety Education. He has served as chairman of the Cleveland Section of A.I.Ch.E., and a member of the National Safety Committee of Alpha Chi Sigma.

MANAGEMENT VIEWPOINTS ON PLANT SAFETY

HAROLD L. MINER

Consultant

Philadelphia, Pennsylvania

DURING many years of investigating personal injuries, reviewing and analyzing thousands of personal injury reports, I have yet to find one—a single personal injury—which could not have been prevented by a little more foresight and more constructive thinking. Management's limited acceptance of its responsibility for the safety of its employees has too frequently resulted in human tragedies, truly needless and preventable.

Now, you ask—"What then is an accident?"

Webster defines an accident as "An event which takes place without one's foresight or expectation; an undesigned, sudden and unexpected event; often an undesigned and unforeseen occurrence of an afflictive or unfortunate character, etc."

There are a number of court decisions which support this definition. The Supreme Court of the U. S. once ruled:

> "If a result is such as follows some ordinary means, voluntarily employed, in a not unusual or expected way, it cannot be called a result effected by accidental means, but if in the act which precedes the injury, something unforseen, unexpected, unusual, occurs, which produces the injury, then the injury has resulted through accidental means."

Another court decision is as follows—

"Accident has in it the element of improbable, unusual, by chance."

Is it not a fact that we are constantly predicting or stating, based upon experience, case histories, or recognized hazards or exposures, that unless the employees follow operating procedures and obey safety regulations, unless the mechanical guards are in place and functioning, unless adequate personal protective equipment has been provided where needed and used, certain employees will probably be injured. Therefore, when injuries do occur, they were not unforeseen, unexpected, or unusual, they did not result from accidents, *and could have been, and should have been prevented.*

Rarely, if ever, are personal injuries to industrial workers caused by accidents as defined. When this is recognized, a more constructive approach to prevention is established. Nothing can justify delay on the part of management to assume responsibility, to safeguard its employees.

During the past quarter century, I have noted with considerable concern, a growing tendency to complicate and involve safety procedures that the programs are robbed of their directness and ease of accomplishment. I believe that a general summation of successful experience, research, and extended thought with regard to the prevention of personal injuries would be characterized by amazing simplicity.

Great accomplishments are usually characterized by simplicity. I have always been partial to the term "simplicity," particularly with reference to safety. It connotes freedom from ornaments, formality, ostentation, subtility, freedom from complexity hence plainness and directness.

I recall a bad landslide which prac-

Courtesy Photographic Lab., Phila. Naval Shipyard

Fire fighters clad in "fireproof" suits entering a gasoline-spill fire. Protective clothing, composed of a five-layer fabric (asbestos-felted Fiberglas-neoprene Fiberglas-flannel lining), is designed to enclose a standard self-contained oxygen-breathing apparatus, permitting the wearers to remain in hot (1400-2000° F.) fire area for nearly 4 min. This is a wartime development of the U. S. Navy.

Courtesy National Board of Fire Underwriters

Evaluation of automatic sprinkler heads under the testing program of the Underwriters' Laboratories. Test operator sets off sprinkler head with flame and the spray distribution pattern is recorded photographically and determined quantitatively by the amount of water collected in the floor buckets over a given period.

Harold L. Miner has directed safety activities of the Du Pont Co. for more than 25 years. During a career which began in 1904 with the National Fire Protective Association in Hartford, Conn., he has done work for the U. S. Government in peace and in war, and has made many contributions to the development of standardized methods for industrial safety and fire prevention. For 35 years he was associated with the Du Pont Co., and served as manager of the engineering department's fire protection division, and later headed a new division which combined all safety and fire protection activities. He is coauthor of the chapter on Safety and Fire Protection in the "Chemical Engineers Handbook." He was a member of the War Department Advisory Council on Fire Protection and the Secretary of Labor's Advisory Committee on Safety and Health Requirements. During World War II, Mr. Miner was a member of the Advisory Committee of the Office of Civilian Defense. He has been active for many years in the American Standards Association and is past chairman of its Safety Code Correlating Committee and a member of several other technical committees. On March 15, 1951, he received an Award of Merit for exceptional service to the cause of safety from the National Safety Council, Chicago, Ill.

Courtesy Newark Evening News

Liquefied petroleum fire and explosion in Newark, N. J., occurring in July, 1951. Some seventy 30,000-gal. storage holders out of a total of 100 were destroyed in a three-day fire.

tically closed off a deep cut on an important transcontinental railroad track. After a survey by engineering and maintenance departments, operations were begun to remove the earth and rock blocking the tracks. To make certain the right decision had been reached, the executives called upon an outstanding engineer to verify the conclusions. After looking over the situation, it is alleged that General Goethals said, "You are on the right track, continue excavating until you reach the 'angle of repose,' and you will have no more difficulties." Just as simple as that!

The prevention of personal injuries is largely, if not entirely, a matter of approach and attitude. There is no magic formula for the prevention of personal injuries. Neither is there a need for such a formula.

The acceptance of responsibility for employee safety by company or plant management may mean a drastic modification of attitude towards the problem.

By attitude, I mean comprehensively that management must understand and fully accept responsibility for the safety of employees. The tension and temper of the times has brought a vital discrimination to the meaning and significance of responsibility, whether it is that of an individual for an individual, or of an individual for a group, whether that group is small or a group composed of many departments. The distinction should be carefully drawn between the terms responsible and responsibility. When one is convinced as to the rightness of a conclusion and carries it into ensuing action, that person can be said to be responsible.

Responsibility entails being held answerable and accountable for the outcome of actions of human beings, laws of living and accepted practices. A responsible person and one who assumes responsibility must be aware of relationships and their probable functioning to a desired end.

If injuries to industrial employees are to be prevented, three fundamentals must be embodied in the plant safety program:

1. Adequate safeguards must be provided, including both mechanical and personal equipment. 2. Employees must understand that they are required to work safely and they must be taught and constantly encouraged to do so. 3. Management, supervision, and the employee must understand, accept, and discharge their respective responsibilities in the prevention of personal injuries.

At one time great emphasis was directed toward the safeguarding of mechanical equipment. This reduced injuries remarkably, but far too many injuries were still occurring because the importance of the second and third fundamentals were not fully appreciated. As manufacturing hazards are safeguarded more attention must be centered upon the workers if *all* injuries are to be prevented.

What should Management's attitude be towards the so-called "accident-prone" employee, and the implication that "age" or "length of employment" must have some bearing upon an employee's susceptibility to injury.

Many years ago the Du Pont management refused to accept accident proneness, age, length of service, etc., as the actual causes of personal injuries. After a thorough analysis of thousands of minor injuries and many major injuries as to cause, it was concluded that "accident-proneness," "age," etc., were really alibis which had been used for so long for ineffective safety programs that they were being accepted as legitimate causes. It was invariably found that the recurrence of injuries to certain employees could be prevented if conditions under which they were working were improved. In some instances it was the question of lighting, in others types of tools or the way they were used, unsafe practices ignorantly followed, carelessness or chance-taking, non-adherence to operating rules and safety regulations, or possibly a physical cause such as defective eyesight.

The alleged causes — accident-proneness, age or length of service —were found to be spurious, for proper training, education and adequate supervision are preventing such injuries.

There is available today effective protective equipment for practically every known hazard to which employees may be exposed. The problem of suitability can be divided into two parts: First, the protection of the hazard at its source.

Holland Tunnel fire of May, 1949. View of trucks which carried 80 drums carbon disulfide (right) and paint supplies (left).

Courtesy Port of New York Authority

This includes guards around gears, belts, and other moving machinery; tight equipment to contain dangerous materials; mechanical ventilating or collecting systems to entrain and remove dangerous gases, vapors, or dust at their point of exit; and others. Second, the protection of the employee. The type of protective equipment needed depends, of course, upon the inherent hazards present—the active and the dormant exposures to be safeguarded.

Factors which should be given considerable attention when selecting the type of protective equipment needed for a hazard or an exposure are:

1. Character of the materials or operations exposing the employee to possible injury. 2. The employee's duties which may bring him into contact with them. 3. The parts of body likely to be injured and nature of the injury.

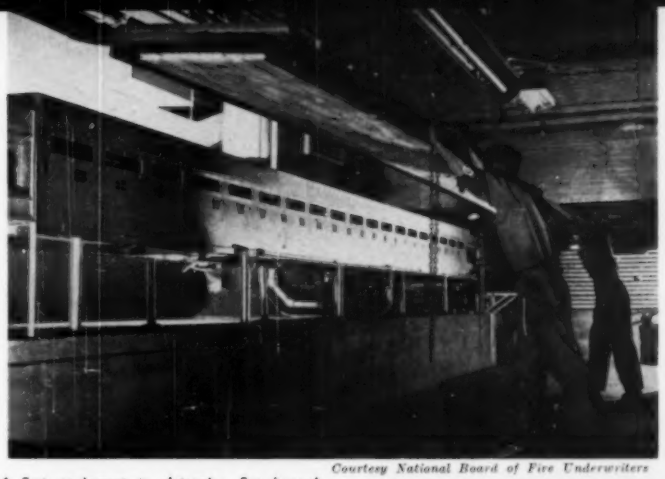
With this information, management can install necessary mechanical safeguards, provide adequate personal protective equipment, formulate safe operating procedures, and train the employee to work safely.

Of course the employer is required by labor department regulations, and by laws to provide safeguards for hazards and exposures. This definitely places the responsibility for preventing certain injuries upon his shoulders. But, a plant fully guarded and protected from a physical standpoint, while unquestionably much safer than one not so guarded, is not immune to serious injuries or fatalities. Safety goes beyond mechanical and physical safeguards. It includes the human element—a most important factor which must not be overlooked.

To prevent all injuries, management must see that each member of the operating personnel—management, supervision, worker—takes his logical place in the safety organization and assumes the full measure of his responsibility for safety.

To the extent each member of the plant force is responsible for plant operations, to that same extent is he responsible for safety.

The manager is responsible for the safety of all plant employees. When a department head is given a job, the safety of every employee goes with it. Each foreman or group leader is responsible for the safety of the employees he supervises, and each workman has the responsibility of doing his job safely.



Courtesy National Board of Fire Underwriters

▲ **Test equipment to determine fire hazard classification of building materials. Observations are made on rate of flame spread, amount of fuel contributed, and volume of smoke produced. Comparative ratings with asbestos-cement board as zero and select red oak as 100, provide a classification scale under standardized conditions of the test. Equipment at Underwriters' Laboratories.**

Courtesy National Board of Fire Underwriters

Inside view of fire test tunnel for evaluating ► fire hazard of building materials. Note test panel in top of unit.

Plant Safety Committees are recognized as probably the best means for securing employees' cooperation, carrying out company safety policies, educating the employees in safe practices, and sustaining their interest in safety.

The staff or central safety committee directs the safety work for the plant as a whole; the departmental committees, extend the work to the foreman; and the foreman committees extend it to all the workmen and make it effective.

Except on small plants (less than 50 employees) the safety organization should include the following: A staff or central committee under the chairmanship of the manager or his assistant, departmental committees, and foreman committees. Office and other nonoperating employees should not be overlooked.

When all divisions of the plant personnel are systematically coordinated in the safety program, as they are united in production, the result is an effective safety organization.

Management and management personnel have and must accept the responsibility to see that the conditions under which the employees work are safe; that all safety devices are in place, in

Warehouse fire at Montreal (Que.) railroad terminal. Spread of uncontrolled fire because of excessive storage areas (lack of fire wall separation) and crowded stock.

Courtesy National Board of Fire Underwriters

Courtesy National Board of Fire Underwriters

Electroplating works blast in Los Angeles, February, 1947, involving a mixture of perchloric acid and acetic anhydride in an electro-polishing bath (failure of a refrigerating system)—with deaths to 17 persons and wrecking 60 buildings.

good repair and functioning; that the necessary personal protective equipment is available and in good condition; and that the employees know how and when to use such equipment and do so.

Supervision must make sure that the employees know that safety is as much a part of their job as is following the established operating procedures, that they know *how* to work safely, and understand that they *are* to work safely.

Supervision must be constant and sincere in its efforts to secure and maintain the employee's sympathetic cooperation in the safety program.

The employee's responsibilities might be summarized as follows:

To work safely at all times, never take chances, never indulge in unsafe practices or do those things which may injure himself or fellow-workers; always to follow operating instructions and safety regulations, to use protective equipment when required, and to report promptly to supervision any unsafe practices or unsafe conditions noted.

To satisfy any misgivings you may have as to the effectiveness of a simple and direct safety program I will briefly sketch several case histories in the prevention of injuries which have resulted from the adoption and operation of the principles and philosophies as outlined in this article.

CASE 1. Some 20 years ago, a large chemical plant of about 2,000 employees, manufacturing metallic sodium, chlorine, chlorinated hydrocarbons and similar compounds, experienced over 80 disabling injuries in one year. When management accepted the responsibility for employee safety in 1931, the plant operated an entire year without a disabling injury. Recently the plant operated over a year and a half—6,000,000 man-hours without a reportable injury.

CASE 2. The frequency rate of a paper mill with over 3,000 employees averaged from 40 to 50 (per 1,000,000 man-hours of exposure) during a five-year period. Top management was alerted and instructed the entire supervisory staff that it was being held responsible for employee safety. In 1942, with a 300% wartime turnover, injuries were reduced from the previous year's 128 to 23, and they are being further reduced each year. One of that company's plants operated the entire year of 1948 without a time-losing injury—an accomplishment believed impossible a few years ago.

CASE 3. A machine shop and foundry, with a force averaging 400, including foundrymen, machinists, pattern makers, pipe fitters, etc., for a 20-year period previous to 1945, averaged 4 disabling or time-losing injuries each year including several fatalities during the span. Starting April, 1945, they operated approximately 4,500,000 man exposure hours without a serious injury, establishing a new world's record for that classification.

CASE 4. A large chemical research and pilot plant laboratory, after management changed its belief that incidents which caused personal injuries were to be expected in this type of work, an attitude which had resulted in a very unsatisfactory safety record, operated over two years, nearly 3,000,000 exposure man-hours, without experiencing a disabling injury.

CASE 5. A modern textile plant, with a force of 1,765 employees established a world's record by operating from beginning of operations, 2,021 days or 18,871,795 man exposure hours without a time-losing or disabling injury, establishing a "world's best no injury record" which stood unsurpassed for five years.

CASE 6. A similar 30% chemical and 70% textile plant with a force of employees averaging 1,500 a year since July 29, 1942 (now about 2,500) recently established a new world's best no-injury record of 28,132,583 exposure man-hours. The record was terminated in February, 1951. This plant has many unusual operating exposures, i.e., high temperatures, corrosive and toxic materials, stock handling and transportation hazards, etc. If during this period injuries had occurred at the same rate as in industry as a whole, over 250 men and women would have been seriously injured, 15 would have been killed or permanently disabled.

In each of the case histories the improvement resulted primarily, if not entirely, from a change in attitude on the part of management, supervision and employees.

The employees establishing these fine records were not psychoanalyzed; cataloged according to aptitude tests, measured for emotional stability; or given a personal, social or intelligent quotient.

There were no sweeping changes in the plants. They were not redesigned or rebuilt, the equipment remained the same, there was no change in materials used or manufactured, and the working force with the usual turnover remained the same. The one specific change which accounted for the great improvement in the safety record was the change in management attitude.

While initial selection of persons for employment should be done carefully in order to insure the placement of the right person in the right assignment the safety program does not include a study of the characteristics of present employees. Supervision generally can be counted upon to have a sufficient knowledge of each worker.

The problem of preventing personal injuries is not complex or difficult. When all employees, from the manager to the individual worker, adopt the proper attitude and seriously determine to prevent personal injuries, personal injuries will cease to occur.

(This and the preceding paper were presented at the A.I.Ch.E. Kansas City meeting.)

PERFORMANCE OF SPINNING DISK ATOMIZERS

Part II

C. R. ADLER† and W. R. MARSHALL, JR.

University of Wisconsin, Madison, Wisconsin

Results

Weight Distribution Results. The data were plotted both as differential and cumulative curves. Attempts to obtain a linear correlation on probability paper were unsuccessful. In order to make some comparison of the results certain arbitrary parameters were chosen. These were: (1) the distance from the disk which included 50% of the spray, (2) the distance which included 90%, and (3) the distance over which the middle 90% of the spray was spread; i.e., the distance between 5% and 95% of the volume as expressed by the cumulative plot.

Figure 16 shows these parameters plotted against feed rate for disk *V*-2. (Figures of disks were run in Part I.) It can be seen that the spread of the spray was substantially independent of the feed rate, while at lower feed rates the whole spray moved in toward the disk. Figure 17 shows the effect on weight distribution of disk peripheral velocity for a feed rate of 25 lb./min. Similar curves were obtained for a feed rate of 50 lb./min.

When vane length, vane height, and number of vanes were varied no significant effects on weight distribution were noted. As a result, plots of weight distribution variables vs. rate of liquid feed per length of wetted periphery were substantially the same as the plots against feed rate.

The width of the feed annulus was changed from $\frac{1}{32}$ in. to $\frac{1}{16}$ and $\frac{3}{16}$ in. for some runs, with no effect on weight distribution. This was reasonable, since the initial velocity of the feed was small compared to the final velocity.

The curved vaned disks gave different weight distributions depending on the direction of rotation. Disk *B*-1 when rotating clockwise—forward leading vanes—did not distribute the liquid as far, probably because more energy was imparted to the liquid, resulting in increased atomization and a decreased distance of travel. The same was found to be true for disk *B*-6.

The effect of varying the amount of air pumped by the disk during spraying was studied. When disk *B*-6 was operated at 8400 rev./min. with no restrictions on air pumping, the distance the liquid was thrown was increased appreciably over that when most of the air was blocked by a brass plate. The position in which this plate was used is shown in Figure 1. The nonvaned and radial-vaned disks pumped negligible amounts of air.

Weight distributions for seven types

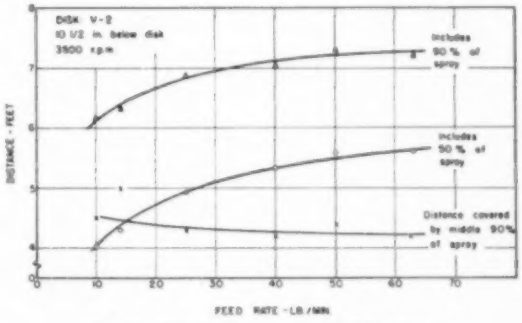

DISK V-2
10 1/2 in. below disk
3500 r.p.m.
Includes 90 % of spray
Includes 50 % of spray
Distance covered by middle 90% of spray
DISTANCE - FEET
FEED RATE - LB./MIN.

Fig. 16. Effect of feed rate on weight distribution.

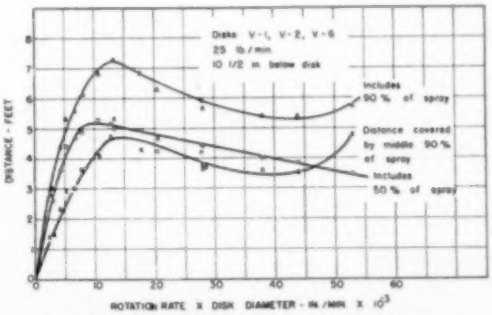

Disks V-1, V-2, V-6
25 lb./min.
10 1/2 in. below disk
Includes 90 % of spray
Distance covered by middle 90 % of spray
Includes 50 % of spray
DISTANCE - FEET
ROTATION RATE X DISK DIAMETER - IN./MIN. X 10³

Fig. 17. Effect of peripheral speed on weight distribution.

Part I of this paper was run in the October issue of "C.E.P."

† Present address: Eastman Kodak Co., Rochester, New York.

Table 1 in its entirety is on file (Document 3365) with American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C. Obtainable by remitting $1.00 for microfilm and $1.00 for photocopies.

TABLE 2

Summary of Results

Drop Size Distribution, Weight Distribution, and Power Requirements

Feed rate: 25 lb./min.
Peripheral velocity of disk: 12,550 ft./min. ± 3%

Drop Size Data:

Drop size, microns \ Disk type	B-1	B-2	B-3	B-4	B-5	B-6	V-2
d_s	105	122	126	100	126	104	116
d_v	119	136	141	114	139	120	131
d_a	152	168	177	150	170	161	170
D_n	79.0	99.8	97.0	72.6	105	70.8	83.5
D_s	150	162	178	145	167	161	169
D_v	172	181	197	170	183	185	190
σ_v	57.1	-	59.0	58.0	52.6	59.9	61.6
σ_s	-	1.42	-	-	-	-	
Weight distribution parameters, feet†:							
50%	8.0	5.1	5.6	6.0	5.8	5.9	5.6
90%	8.0	6.6	7.2	8.1	7.8	8.4	7.6
5-95%	6.0	5.2	5.5	5.6	6.8	7.0	6.0
Power and efficiency data:							
P_E, kw.	0.79	0.54	0.69	0.72	0.75	0.70	0.78
R, sq.ft./min.	4810	4370	4140	4890	4320	4560	4320
$(P_E/R) \times 10^3$ kw./(sq.ft./min.)	0.164	0.123	0.167	0.147	0.174	0.153	0.180
E, percent	0.68	0.90	0.67	0.76	0.64	0.73	0.62

† These figures represent the radial distances from the disk, which include 50%, 90%, and the middle 90%, i.e., from 5 to 95%, of the mass of the spray.

of disks on which drop-size-distribution data were obtained are shown in Figure 18. For the most part the distributions are quite similar, with *B*-2 yielding the pattern with the least spread and closest to the disk and *B*-6 giving the other extreme. Parameters for comparison of these distributions are listed in Table 2 for the same feed rate and peripheral velocity.

Drop-Size Distribution Results. Drop-size-distributions curves plotted on a cumulative volume basis are shown in Figure 19 for the seven disks tested. This type of plot proved to be most successful. Six types of average diameters were calculated. The most useful is believed to be the d_a average diameter based on the ratio of volume to surface area, of Equations (17) and (18), since this is useful for calculating rates of heat and mass transfer.

A plot of cumulative size distribution on a volume basis was considered the most informative because it showed how the weight of the liquid was distributed among the various drop-size ranges. This plot also yielded a straight line on arithmetic probability paper (Fig. 19) with the exception of data from disk *B*-2, which was linear on log probability paper. The standard deviations for these curves were taken as a measure of the uniformity of the distribution, and are given in Table 2.

The efficiency and rate of surface creation were calculated for each disk as described in the previous section. These results together with the ratio between the net power used and the power for surface creation only are listed in Table 2.

No correlation between the calculated theoretical film thickness of the liquid as it left the disk and the average drop diameters could be found.

A desirable correlation would be one relating drop-size distribution to weight distribution to minimize the amount of drop-size data to be taken. However, it seems likely from the present work that a different relationship would result for different disk types.

The average drop volume, v', at each sample point for each spray varied in a systematic manner, and in the same way for each spray. The data for disk *B*-1 (Fig. 20) indicated that small drops predominated close in and far out from the disk, while the large drops, less affected by air currents, settled out mainly in the middle distances. However, this was an over-all effect, and large and small drops were found at all distances.

Power Correlation. Net power was correlated with two objectives in mind: (1) to check Equation (4), and (2) to evaluate the effective feed position on vaned disks. The latter may need some explanation. Liquid feed was actually introduced onto the disk directly beneath the feeder. However, when vanes were used to prevent slippage, they usually did not begin until farther out on the disk. Hence there was some slippage between the feed point and the beginning of the vanes. The effective feed point would be that one which resulted in the same power consumption and gave the same liquid velocity with-

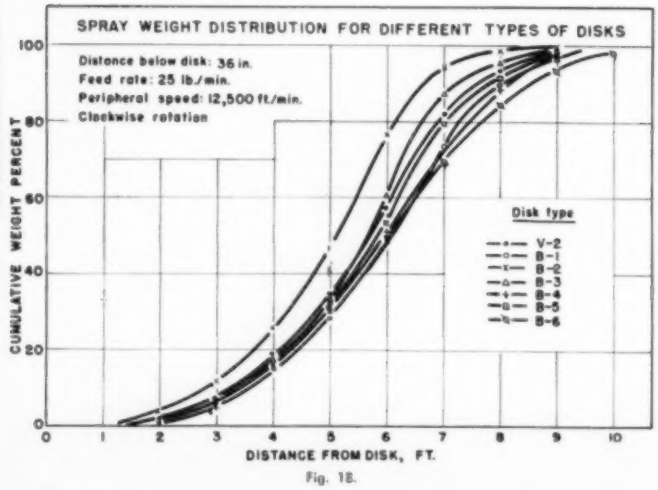


Fig. 18.

out slippage as the actual feed point did with slippage.

Figure 21 was plotted from the power data for radial-vaned disks.

Expressing the disk diameter, d, and initial feed point diameter, d_o, in inches, the theoretical equation reads:

$$P_k = 1.33(10^{-11})\omega N^2[d^2 - (\tfrac{1}{4})d_o^2] \quad (25)$$

From the intercept when $P_k = 0$, $d^2 = (\tfrac{1}{4})d_o^2 = 1.0$, and $d_o = 1.4$ in. The diameter of the feeder was 1.2 in. From the slope of the experimental curve, an empirical constant was evaluated which gives the empirical equation

$$P_k = 1.25(10^{-11})\omega N^2[d^2 - (\tfrac{1}{4})d_o^2] \quad (26)$$

This indicates the experimental values to be 6% less than theoretical. The theoretical power was calculated and is shown plotted in Figure 21.

The data on power consumption for all the disks—smooth, curved and straight vaned—appear in Figure 22. Considering that d_o varied from one type of disk to another; i.e., the amount of slippage was different, the agreement was considered good.

Rotating disks pump air, the amount of air depending on disk design. Designs similar to *B*-3 and *B*-4 will pump little or no air, while *B*-6 and *B*-1 will pump a relatively large amount. In this respect, the positioning and shape of the vanes are very important. Power data were taken for rotating disks with the air inlet zones open and also with them blocked to minimize air flow through the disk. The runs were made for a range of rotation rates with no liquid fed to the disk. The data were plotted as shown in Figure 23. The importance of the direction of vane curvature is shown for disk *B*-1 which was rotated in both directions.

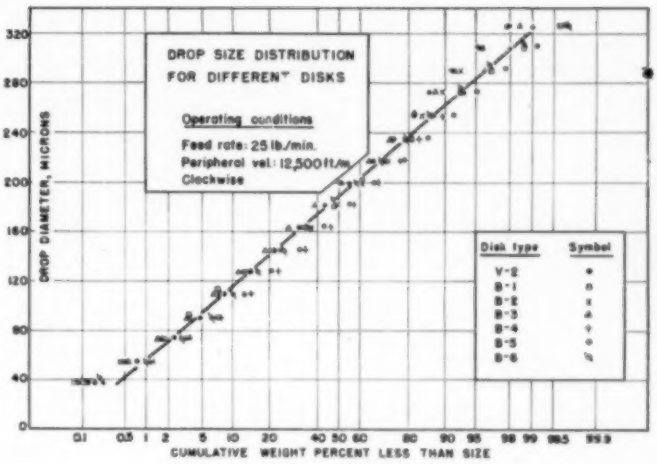


Fig. 19.

Pumping air is of no apparent value to an atomizer; it only uses power, and in spray drying may cause material to dry on the disk. Air should be left to circulate around the disk to break up currents which could recycle the spray, but this can be done without pumping air through the disk.

Liquid Velocity and Break-Up. In most instances the measured power did not equal the theoretical maximum because the liquid did not achieve maximum theoretical velocity due to slippage and frictional forces.

The trajectory and flow pattern of the liquid as it left the disk changed with a change in the ratio of radial velocity to peripheral (Fig. 2). However, this change was so slight before break-up occurred and was so easily affected by air currents that it was ineffective as a guide to the determination of liquid velocity. From experimental power data, it was estimated that the radial velocity might have been as high as 94% of the peripheral velocity for vaned disks.

Photographs of the flow patterns were taken for some sprays with a GE high speed light having a peak light intensity for two millionths of a second (Figs. 24-27). Figure 24 shows a radial vaned disk with atomization by direct film formation and its subsequent break-

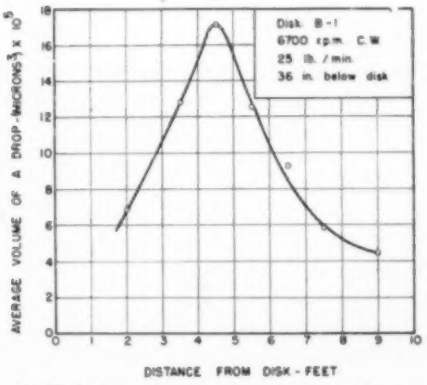


Fig. 20. Variation of average drop volume with distance from disk.

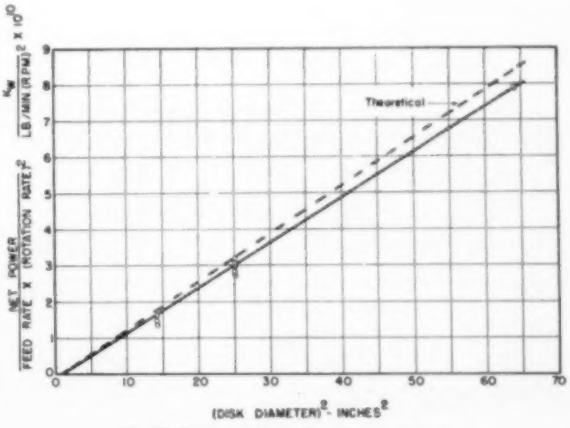


Fig. 21. Power correlation for radial vaned disks.

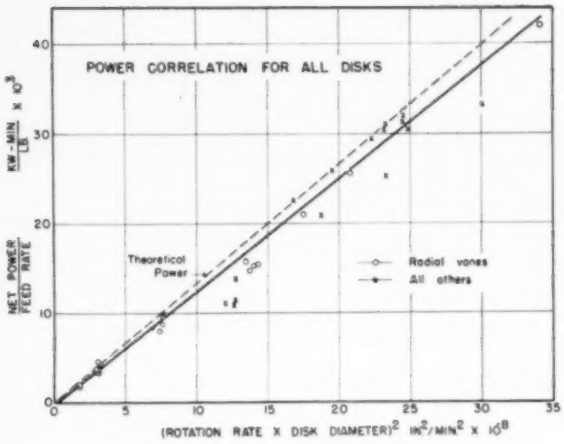

POWER CORRELATION FOR ALL DISKS
NET POWER / FEED RATE — KW-MIN/LB x 10^3
Theoretical Power
Radial vanes
All others
(ROTATION RATE X DISK DIAMETER)^2 IN^2/MIN^2 x 10^8

Fig. 22.

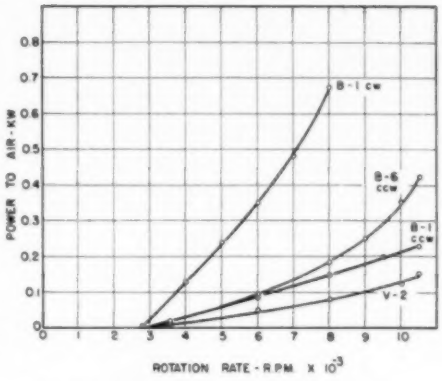


Fig. 23. Effect of rotation speed on power to pump air.

TABLE 3

Specifications of Disks

Designation	Diam., in.	Vane height, in.	Vane length, in.	No vanes
V-1	3.75	0.375	0.375	24
V-2	5.0	0.375	1.0	24
V-3	8.0	0.312	2.5	24
V-4	5.0	0.656	1.0	24
V-5	5.0	1.281	1.0	24
V-6	8.0	0.375	2.5	24
V-7	5.0	0.375	0.625	24
V-8	5.0	0.375	1.625	24
V-9	5.0	0.375	1.0	20
V-10	5.0	0.375	1.0	16
Lucite	8.0	0.375	3.0	20
B-1	7.0	0.406	1.0	60
B-2	5.0	2.25	1.0	18
B-3	7.0	-	-	-
B-4	5.0	0.625	-	-
B-5	7.0	-	-	-
B-6	6.0	-	-	-
B-7	5.0	-	-	-

up into ligaments and then drops. Figure 25 shows *B*-3 producing ligaments directly. In Figure 26, the irregular pattern of ligaments and globs of liquid obtained from a smooth disk, *B*-5, can be seen. These pictures were taken for feed rates of 25 lb./min. and disk speeds of about 7600 rev./min.

At low angular velocities somewhat different results were noted. Figure 27 shows disk *B*-1 rotating at 470 rev./min. with a feed rate of 10 lb./min. It appears that air was included in a film in irregular shapes which broke up into ligaments or drops. A continuous film was observed for feed rates up to 25 lb./min.

The calculated values of radial velocity (Eq. (9)) were plotted against radius as shown in Figure 28. It can be seen that the value of r_o, the feed point, is not critical in evaluating velocities after a few inches of travel. This is another explanation as to why the power requirements were not affected much by a change in feed point or the length of the vanes.

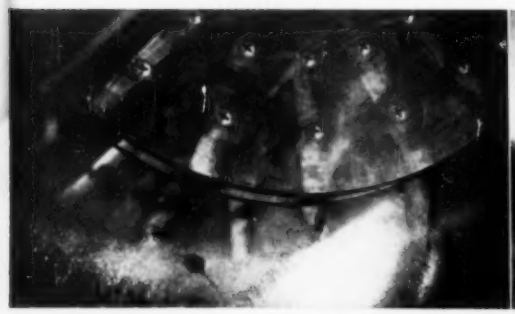


Fig. 24. Liquid break-up from a Lucite radial vaned disk. Ligament formation is evident.

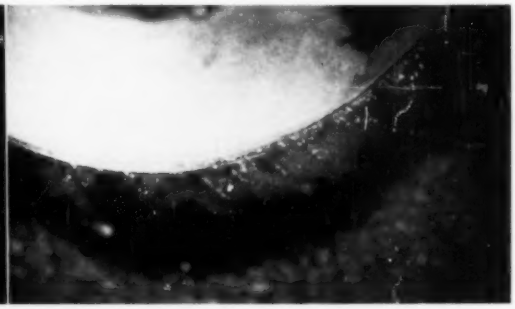


Fig. 25. Liquid break-up from a double smooth disk, B-3. Ligament formation is evident.

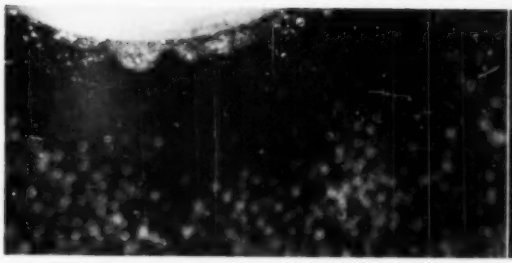


Fig. 26. Irregular break-up from a smooth disk.

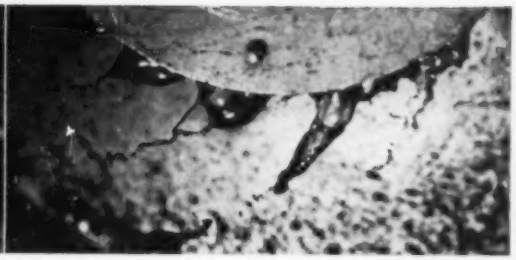


Fig. 27. Film formation followed by ligament formation obtained at low disk speed on vaned disk, B-1.

Solutions were also obtained for various values of A (Fig. 29). It can be seen that the effect of A increases with the distance from the feed point. This parameter includes the effect of the frictional drag and hence liquid viscosity, at the liquid disk interface.

From experimental values of liquid radial velocity at the disk periphery the value of A for any set of conditions could be obtained by an interpolation process. When $A = 0$, the case of no frictional resistance, the maximum energy would be imparted to the liquid.

As the distance along the radius becomes large, the importance of the first term of Equation (9) becomes negligible in calculating velocity and the equation approaches the form of the cubic equation

$$v_r^3 = \frac{\omega^2 r}{A} \qquad (27)$$

A more exact expression was determined empirically, and is given as follows:

$$z = x^{1/3} - \frac{1}{9x} - \frac{1}{27x^{4/3}} - \frac{62}{218x^{5/3}} \qquad (28)$$

where

$$x = A^{1/6}\omega^{1/3}r$$

and

$$z = A^{1/6}\omega^{-1/3}v_r$$

The asymptotic expansion in Equation (28) is valid only for large values of x. For values of x greater than one, the error of the approximation is less than one half of one per cent.

Values of the friction factor should be obtainable from experimental values of A. However, it was felt that liquid velocities calculated from power data were unreliable. Therefore, better experimental methods must be developed to determine radial velocities more precisely if the above equations are to be useful for this purpose.

Comment and Conclusions

While no drop-size data were taken for all the conditions used in correlating weight distribution data, explanations of the trends observed can be made on the basis of the expected changes in drop size. With reference to Figure 16, it seems logical to explain the correlations on the basis that at lower feed rates thinner films would be formed to give smaller drops that would not travel as far as larger ones formed at higher feed rates.

It can be hypothesized (Fig. 17) that increased liquid velocities should result in finer atomization, and higher initial drop velocities from the disk. The resulting weight distribution, however, would depend on how rapidly the droplets lose their velocity. Starting at a value of 10 on the abscissa of Figure 17, it appears that an increase in disk velocity resulted in shorter distances of travel, implying greater deceleration of the drops due to smaller drop size.

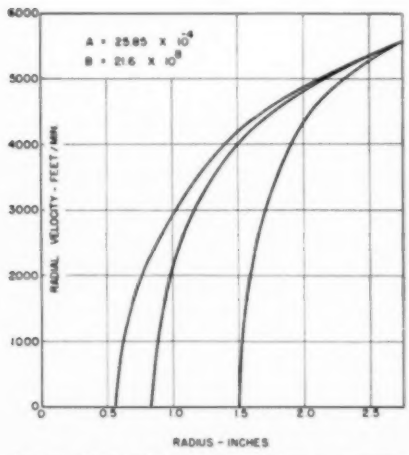


Fig. 28. Liquid radial velocity. Solutions to theoretical Equation (9). Effect of variation of the liquid feed point.

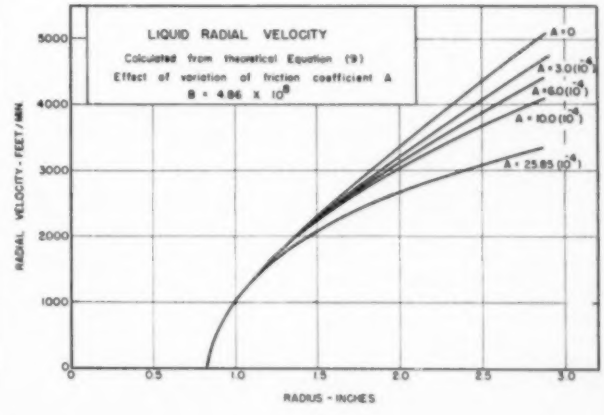

LIQUID RADIAL VELOCITY
Calculated from theoretical Equation (9)
Effect of variation of friction coefficient A
B = 4.86 X 10⁸
A = 0
A = 3.0(10⁻⁴)
A = 6.0(10⁻⁴)
A = 10.0(10⁻⁴)
A = 25.85(10⁻⁴)
RADIAL VELOCITY - FEET / MIN.
RADIUS - INCHES

Fig. 27.

However, when some drops become very small they are easily carried by air currents, causing an outward shift in weight distribution above a certain disk speed. At values of the abscissa less than 10 the distance of spray travel decreased with disk speed until finally, near the origin, the liquid simply spilled over the edge of the disk.

While no effects on weight distribution due to a variation of vane length were noted, it might have been expected that the distributions should have moved closer to the disk for longer vanes, because with less slippage the liquid velocities would be higher and atomization finer. It appeared, however, that if this effect existed it was so small as not to have been detectable in the correlations. It was also predicted from the solution of the liquid velocity equation, Equation (9), that an increase in vane length would produce a negligible increase in liquid velocity above a certain disk size.

It is possible that film thickness affects drop size and weight distribution at low feed rates and disk speeds where the literature (*18, 54*) has indicated atomization occurs by direct drop formation. The high degree of drop-size uniformity so reported was not obtained for the operating conditions used in this study. It is believed that this was due to the fact that atomization was due almost entirely to break-up by liquid-air friction.

Atomizing Characteristics of the Disks. There were no marked differences in the drop-size characteristics of the sprays produced for a single set of conditions by the different designs of disks studied in this project. It should be noticed, however, that the smooth disk with disintegrating blades along the periphery, *B*-4, produced the smallest average drop size and, hence, had the greatest rate of area creation, while the smooth disk with the vertical knife edge around the periphery, *B*-3, produced the spray with the largest average diameters. The greatest uniformity of drop size was obtained with the smooth cone-shaped disk, *B*-5.

The disk with backward-leading vanes, *B*-2 gave a spray that covered the least area. Moreover, it spread the liquid over this area with the most uniformity. This disk was of relatively crude construction, made of cast aluminum with rough, unfinished surfaces. Still, it proved to be decidedly the most economical to operate, having the highest efficiency of surface creation and lowest expenditure of power per unit of surface created. Also, on the basis of surface created the disk with radial vanes, *V*-2, was least economical. However, the over-all difference among all the disks was actually small. (Table 2.) Disk *B*-2 was also the only one which gave a logarithmic drop-size distribution. All the others gave normal arithmetic distribution.

The theoretical power equation proved to be suitable for estimating the net power requirements for disk atomizers. The empirical equation accounting for frictional losses is recommended for design purposes, although the theoretical equation gives suitable conservative estimates.

The drop-sampling technique was believed to be as reliable as any physical sampling procedure can be. It was considered satisfactory for the smallest drops because the samples were collected in a region of essentially zero air velocity. Moreover, since small drops were not numerous in the sprays produced in this study, the errors in their collection would not be very serious. This was indicated by the smooth shape of the curve as it approached the lower size classes.

A summary of the results and conclusions from this study are as follows:

1. No outstanding difference in the drop-size characteristics of the sprays produced by disks of different designs could be detected for the condition tested. This implies that further studies of operating variables on a single type of disk should apply to a wide variety of disk designs.

2. Net power calculated from the theoretical equation, Equation (25), for all the types of disks agreed well with measured values, and this equation can be used for design purposes. For greater precision, the empirical Equation (26) is recommended.

3. When air was pumped by the disks, the power consumed increased considerably. There was no reason to believe, however, that there were any compensating beneficial effects, such as improved atomization.

4. The spray weight distribution decreased with peripheral velocity at low disk speeds and changed but slightly at high speeds, while the effect of feed rate was inconclusive, no appreciable change in weight distribution being noted over a seven-fold variation in feed rates.

5. Over the range of operating conditions tested, atomization was preceded by ligament and/or film formation; therefore, the relative velocity between liquid and air would be expected to be of greater influence on the drop size than the centrifugal force exerted on the liquid. This mechanism of atomization does not create a spray of highly uniform drop size.

6. Feed position appeared to have no effect on radial velocity. A theoretical development showed this result to be expected for disks greater than 5 in. in diameter.

7. From the same theoretical development it was concluded that liquid viscosity and frictional resistance at the liquid-disk interface becomes significant for disks greater than 3 in. in diameter.

Acknowledgments

The work of Dr. A. M. Mark and the University of Wisconsin Computing Service on the machine solutions of the equations presented in this paper is greatly appreciated.

Financial aid received from the Wisconsin Alumni Research Foundation, Du Pont Co., Inc., and the American Cyanamid Co. is gratefully acknowledged.

Acknowledgment is also due the Bowen Engineering Corp. and the Du Pont Co. for the use of several of the disks used in the experimental work.

The authors are also grateful to O. A. Hougen and K. M. Watson for their helpful suggestions.

Notation

A = coefficient depending on friction, operating conditions, and disk design
b = vane ht., ft.
c = number of vanes
D_n = mean drop diam. on a number basis, μ
D_s = mean drop diam. on a surface area basis, μ
D_v = mean drop diameter on a volume basis, μ
d = disk diam., in.
d_a = average drop diam. on a ratio of volume to surface area
d_n = average drop diam. on a number basis, μ
d_o = diam. at point of feed, in.
d_s = average drop diam. on a surface area basis, μ
d_v = average drop diam. on a volume basis, μ
E = efficiency of surface creation
f = friction coefficient
g_c = gravitational conversion factor
m = maximum film thickness at any point, ft.
N = disk rotation rate, rev./min.
n = number of drops
P = net power, ft.-lb./min.
P_h = net power, kw.
P_m = gross power, kw.
P_{wfc} = power consumed by windage, friction, and core losses
P_{cu} = copper losses of motor

q = volumetric feed rate per vane, cu.ft./min.

R = rate of surface creation, sq.ft./min.

r = radial distance on disk from the center of rotation, ft.

r_o = radius at point of feed, ft.

t = transit time, min.

v = velocity of liquid as it leaves the disk, ft./min.

v_r = radial velocity of liquid, ft./min.

v' = average drop volume for a sample point, micron^3

w = mass feed rate, lb./min.

y = distance into the film from vane face, ft.

SYMBOLS HAVING VARYING SUBSCRIPTS

D = arithmetic mean diameter of the size class

F = numerical fraction of drops for one sample in a size class

s = average surface area of a drop in a size class, micron^2

v = average volume of a drop in a size class, micron^3

SUBSCRIPTS FOR THESE SYMBOLS

1.2 . . . numbers indicating the size class

GREEK LETTERS

μ = liquid viscosity, lb./ft.-min.

ρ = liquid density, lb./cu.ft.

σ = surface tension, dynes/cm.

σ_g = standard deviation for logarithmic distribution

σ_y = standard deviation of arithmetic distribution, μ

ω = angular velocity of the disk, min.$^{-1}$

Literature Cited

1. Austin, J. B., *Ind. Eng. Chem., Anal. Ed.*, **11**, 334 (1939).
2. Bär, P., D. Eng. Thesis, Technical College, Karlsruhe, Germany (1935).
3. Bowen, W. S., *Ind. Eng. Chem.*, **30**, 1001 (1938).
4. Bradley, C. E., and Coffin, J. G., U. S. Patent, 1,428,526 (Sept. 12, 1922).
5. Bryan, H. F., *Automobile Eng.*, **31**, 337 (1941).
6. Castleman, R. A., *Phys. Rev.*, **35**, 1914 (1930).
7. Castleman, R. A., *J. Research, Nat. Bur. Standards*, **6**, 367 (1931).
8. Castleman, R. A., *Nat. Advisory Comm. Aernaut., Rept.* No. 440 (1932).
9. Castleman, R. A., *Phys. Rev.*, **55**, 592 (1939).
10. DeJuhasz, K. J., Zahn, O. F., and Schweitzer, Penn State Coll. *Bull.* No. 40 (1932).
11. Deutsche Gold u. Silber Gsheideanstalt, British Patent 509,073 (July 25, (1939).
12. Green, H., *J. Franklin Inst.*, **192**, 637 (1921).
13. Green, H., *J. Franklin Inst.*, **204**, 713 (1927).
14. Haenlein, A., *Nat. Advisory Comm. Aernaut., Tech. Mem.*, 659 (1932).
15. Hartmann, L. F., M.S. Thesis, Kansas State College (1947).
16. Hatch, T., *J. Franklin Inst.*, **215**, 27 (1933).
17. Hatch, T., & Choate, S. P., *J. Franklin Inst.*, **207**, 369 (1929).
18. Hinze, J. C., and Milborn, H., Delft Publication No. 101, Delft Lab., Royal Dutch Shell, Delft, Holland (1948).
19. Houghton, H. G., *Physics*, **2**, 467 (1932).
20. Houghton, H. G., and Radford, W. H., *Papers Phys. Oceanog. Meteorol., Mass. Inst. Technol. and Woods Hole Oceanog. Inst.*, **6**, Nos. 3, 4 (1938).
21. Kinoshita, M., Uchiyama, K., *Sci. Papers Inst. Phys. Chem. Res.* (Tokyo), **391**, 144 (1932).
22. Kuehn, R., *Motorwagen* (Germany), **27** (July, Oct., Nov., Dec. 1924); **28** (Jan. 1925); also *Nat. Advisory Comm. Aernaut., Tech. Mem.*, 329 (1925).
23. Lapple, C. E., and Shepherd, C. B., *Ind. Eng. Chem.*, **32**, 302 (1940).
24. Lee, D. W., *Nat. Advisory Comm. Aernaut. Tech. Repts.*, 425 (1932).
25. Lewis, H., *Ind. Chemist*, **10**, 439, 499 (1932).
26. Littaye, M., *Chaleur & Ind.*, **28**, 3 (1947).
27. Longwell, J. P., D.Sc. Thesis, M.I.T. (1943).
28. Loveland, R., and Trivelli, A. P., *J. Franklin Inst.*, **204**, 193, 377 (1927).
29. Marshall, W. R., and Seltzer, E., *Chem. Eng. Progress*, **46**, 501; **46**, 575 (1950).
30. Nolan, J. J., and Enright, J., *Proc. Royal Dublin Soc.*, **17**, 1 (1922).
31. Nyrop, J. E., *J. Soc. Chem. Ind., (London)*, **48**, 136T (1929).
32. Perrot, G. St. J., and Kinney, S. P., *J. Am. Ceram. Soc.*, **6**, 417 (1923).
33. Philip, T. B., *Trans. Inst. Chem. Engrs. (London)*, **13**, 107 (1935).
34. Probert, R. P., *Phil. Mag.*, **37**, 94 (1946).
35. Rayliegh, J. W. S., *Proc. London Math. Soc.*, **10** (1878).
36. Reavell, J. A., *Chemistry & Industry*, **5**, 925 (1927).
37. Reavell, J. A., British Patent 365,342 (April 21, 1932).
38. Riley, C. L., U. S. Patent, 1,624,847 (April 12, 1927).
39. Riley, C. L., U. S. Patent 1,676,113 (July 3, 1928).
40. Riley, C. L., U. S. Patent 1,732,110 (Oct. 15, 1929).
41. Riley, C. L., U. S. Patent 1,759,629 (May 20, 1930).
42. Riley, C. L., U. S. Patent 1,779,336 (Oct. 21, 1930).
43. Rupe, J. H., Third Symposium on Combustion (Univ. of Wisconsin, 1948), Williams and Wilkins, Baltimore (1949).
44. Sauter, J., *Z. Ver. deut. Ing.*, **70**, 1040 (1926); also *Nat. Advisory Comm. Aernaut., Tech. Mem.*, 390 (1927).
45. Sauter, J., *Forsh. Gebiete Ingenieurw.*, No. 279 (1926); also *Nat. Advisory Comm. Aernaut. Tech. Memo.* No. 396 (1927).
46. Sauter, J., *Z. Ver Deut. Ing.*, **72**, 1572 (1928).
47. Scheubel, F. N., "Jahrbuch der Wissenschaftlichen Gessellschaft Luftfahrt," 140 (1927); also *Nat. Advisory Comm. Aernaut. Tech. Memo.* No. 644 (1931).
48. Schmidt, J. M., Lecture Notes, Jet Propulsion Lab., California Institute Tech. (1947).
49. Schweitzer, P. H., *J. Applied Phys.*, **8**, 513 (1937).
50. Skinner, D. G., and Boas-Traube, S., Paper presented at Symposium on Particle Size, *Inst. Chem. Engrs. & Soc. Chem. Ind. (London)*, (1947).
51. Stoker, R. L., *J. Applied Phys.*, **17**, 243 (1946).
52. Strazhevisky, I., *Tech. Phys. U.S.S.R.* **4**, 978 (1937).
53. Wallman, H., and Blyth, H. A., Paper presented at Houston meeting of A.C.S. (1950).
54. Walton, W. H., and Prewett, W. C., *Proc. Phys. Soc.*, **62B**, 341 (1949).
55. Williams, A. E., *Engineer*, **179**, 374 (1945).
56. Wilson, H., Page, G. A., and Cartwright, V. S., *U. S. Bur. Mines Repts. Investi.*, No. 3248 (1934).
57. Work, L. T., *Bull. Am. Ceram. Soc.*, **17**, 1 (1938).

Discussion

R. A. Jensen (Battelle Memorial Institute, Columbus 1, Ohio): I noticed that the paper does not consider smooth flat disks, which are said to produce more uniform drop-size distributions. Since your paper does not show this characteristic with other types of spinning disks, was any information obtained with a smooth flat disk that would confirm or deny the production of a uniform drop-size distribution?

C. R. Adler: If your reference is to a perfectly flat disk and not to smooth conical or dish-shaped disk, I have no data to offer. The smooth, flat disks were judged to have too much slippage to be practical.

R. S. Bowles (Proctor & Gamble, Ivorydale, Ohio): You say the atomization is done largely by the relative difference in velocity between the liquid stream and the air. Is it to be inferred then that if the air were moving and the liquid relatively stationary, you would get the same weight distribution, the same degree of atomization?

C. R. Adler: That depends on how you would produce the relative motion. If, for example, you were to blow air over water in a pan, I would expect different results, because the atomization definitely depends on the way the liquid is presented to the air. There can be little doubt, but that the fact that we are working with thin films from the disks is a definite aid to atomization. It would be difficult, I imagine, to duplicate the conditions of this work by moving the air and not the liquid; although, if it could be done, I see no reason why you would not get the same type of weight and drop-size distributions. Incidentally, the relative liquid-air velocities are not easy to determine, because the air is in a constant swirling motion.

M. L. Gernert (Tennessee-Eastman Corp., Kingsport, Tenn.): Why did you use that speed of the disk? What would happen at a higher rate or a lower rate of speed in regard to power requirements and the degree of atomization? Some disks are run as high as 33,000 rev./min.

C. R. Adler: The speed used was chosen as being quite representative of industrial applications. It is a large job and one that is now being worked on at the University of Wisconsin, to relate operating variables such as liquid feed rate and disk speed to the drop-size distribution. Of course the effects of these variables on the power requirements were shown in Equation (26).

H. F. Johnstone (University of Illinois, Urbana, Ill.): The additional data on the atomization of liquids are of considerable interest. It has been known for some time that spinning disk atomizers produce more uniform sprays than hydraulic nozzles. The laboratory instruments developed by Walton, to which the authors refer, have been further modified as described in a later paper by May (*1*) to give rotor speeds up to 240,000 rev./min. This will produce uniform droplets from 10 to 150 μ in diameter. Under carefully controlled conditions, 90% of all the droplets are within 5% of the main width of the band. By atomizing dilute solutions or suspensions, uniform residues of solid particles can be obtained. These devices are obviously useful in aerosol studies.

The authors' work was confined to larger disks operating at higher capacities. Even here the degree of uniformity is comparable with that obtained with the best air atomizing nozzle. The mean drop size, however, is considerably larger than those obtainable from pneumatic nozzles.

Table 2 shows the values of $d_n x$ ranging from 150 to 177 μ for feed rates 25 lb./min. and peripheral disk speeds of 12,550 ft./min.

Air atomizers produce droplets of the same uniformity in the range from 20 to 80 μ volume-surface average diameter, whereas the best atomization obtained with hydraulic nozzles operating at high pressures appears to be in the range of 50 to 80 μ average diameter and the uniformity of these is not nearly so good as with the air atomizing nozzles or the spinning disk.

For high speed pictures shown in the paper, as well as the comparative homogeneity of the resulting spray, it appears that the mechanism of atomization is the same in pneumatic nozzles as from the spinning disk, that is, the breakup of the liquid is caused by the frictional drag of the air passing the surface.

It would be interesting if the authors would compare the power required by the spinning disk with that for pneumatic nozzles to give the same average drop size. Apparently the pneumatic nozzle requires less power at least in the limited range of data reported in Table 2.

C. R. Adler: The work of May was conducted at low feed rates where I believe atomization occurred by direct drop formation. These conditions gave excellent uniformity—small drops which fell in a small distance range, with a few satellite drops falling closer to the disk. This, I think, fits in with what has been said. We operated at higher feed rates and observed the air frictional effect.

Unfortunately there are no data on pressure nozzle atomization at present that afford ready comparison with the data for disk atomizers.

H. Wallman (American Cyanamid Co., Stamford, Conn.): You mentioned a paper by Blyth and me on the control of particle size in a spray dryer. We operated in the range of up to 4 lb./min. and 6-in. diam. wheel, and we obtained fairly good uniformity. We believe this was due to the fact that we were operating in the range of direct drop formation where air friction was not controlling. This has been more or less confirmed in our case when materials are transferred to plant spray dryers; at much higher feed rates we do not obtain as uniform a product as reported in the above-named paper.

C. R. Adler: I am glad that you agree; and that at higher feed rates you did get a less uniform product indicating that the mechanism of atomization may change as suggested.

R. L. Pigford (University of Delaware, Newark, Del.): I noticed that the actual measured power delivered to the fluid was some 6% smaller than the power calculated by computing the kinetic energy of the spray. I would have thought that the actual power might have been larger because some work has to be expected in overcoming fluid friction on the disk. What is the explanation for the experimental finding that the power was some 6% less than the theoretical rate of production of kinetic energy?

C. R. Adler: The reason the theoretical power was not obtained is because the slippage and friction on the disk prevented the liquid velocity from attaining the theoretical maximum, and when you do not get velocity you do not use kinetic energy to bring the liquid up to that velocity; therefore the energy requirements are less than theoretical.

Literature Cited

1. May, K. R., *J. Applied Physics*, **20** 932 (1949).

(Presented at Forty-third Annual Meeting, Columbus, Ohio.)

LETTER TO THE EDITOR

Multicomponent Rectification

Sir:

Underwood's methods for calculating multicomponent rectification have been discussed in your pages (**44** No. 8, pp. 603-14; **46** No. 1, pp. 48-54). One device for broadening their application has not been mentioned, so far as I know. This is the use of fictitious molecular weights where components have widely differing molar latent heats.

This device may be employed as follows:

1. Use the actual molecular weight of one component.
2. Calculate for each additional component a fictitious molecular weight that gives, in combination with the experimental latent heat at column pressure, the same molar latent heat as that of the first component.
3. Re-calculate molar flows and compositions of all feed and product streams, using the molecular weights arrived at above.
4. Apply Underwood's equations to the flows and compositions in terms of fictitious mols. (Note that the values of relative volatilities need not be changed, since the same correction factor would be applied to both numerator and denominator.)
5. When a satisfactory design has been reached, the true composition and flow of any stream may be found by converting back to actual mols.

Most of the approximations of Underwood's methods are not removed by the above procedure. Constant relative volatilities, negligible heats of mixing, and compensating sensible heats of liquid and vapor are still assumed.

Robert D. Rayfiel
New York, N. Y.

AN EMPERICAL EQUATION FOR THERMODYNAMIC PROPERTIES OF LIGHT HYDROCARBONS AND THEIR MIXTURES

REDUCTION OF EQUATION TO CHARTS FOR PREDICTION OF LIQUID-VAPOR EQUILIBRIA

MANSON BENEDICT†, GEORGE B. WEBB‡, LOUIS C. RUBIN, LEO FRIEND

The M. W. Kellogg Company, Jersey City, New Jersey

3. Final Charts

3.1 Description of Charts. Each of the final charts refers to a particular component at a particular constant pressure. At pressures up to and including 1000 lb./sq.in.abs. charts representing K-values have been prepared. At pressures between 1000 and 3600 lb./sq.in. abs., inclusive, the fugacity coefficient is the property represented.

In all, 324 charts were prepared for these 12 hydrocarbons at 26 pressures between 14.7 and 3600 lb./sq.in.abs. The temperature range from −100° to +400° F. and the molal average boiling point range from −255° to +180° F. are covered.

Figures 5, 6, 7 and 8 are typical examples of the charts of K-values used in the range of pressures between 14.7 and 1000 lb./sq.in.abs. These examples refer to a pressure of 550 lb./sq.in.abs., and give K-values for methane, ethane, propane and *n*-butane, respectively. The K-values were computed from tables such as Table 9 by the equation:

$$K = \frac{(f^L/x)}{P(f^G/Py)} \qquad (4)$$

The main chart is a plot of the K-value against temperature for lines of constant molal average boiling point of the liquid phase. The insert is a correction factor by which the K-value is to be multiplied to take into account the effect of the vapor-phase composition. In the insert the correction factor is plotted against molal average boiling point of the vapor for lines of constant temperature. For each component, changes in the molal average boiling point of either the gaseous or the liquid phase may affect the K-value by as much as a factor of two.

Above the critical pressure of the pure hydrocarbons making up these mixtures it is impossible to say with certainty whether a state characterized only by its temperature, pressure and molal average boiling point is liquid or vapor. The type of plot shown in Figures 5-8 is less convenient at higher pressures because of this lack of distinction between liquid and vapor phases. Instead, the type of plot shown in Figures 9-12 is preferred at and above 1000 lb./sq.in.abs. These examples refer to a pressure of 1000 lb./sq.in.abs., and give fugacity coefficients of methane, ethane, propane and *n*-butane, respectively. As shown by Figure 9, which refers to methane, the fugacity coefficient is plotted against temperature for lines of constant molal average boiling point. Qualitatively, it may be said that points at low temperatures and high molal average boiling points, at the top of the figure, refer to liquid, and those at high temperatures and low molal average boiling points, at the lower right, refer to vapor; but there is no sharp line of demarcation between the two phases. It is thus possible for K-values read from this type of chart to approach unity at the critical point, where liquid and vapor compositions become identical.

The following example illustrates how a K-value is read from this plot. Let us assume that the temperature is 200° F., the pressure is 1000 lb./sq.in. abs., and the molal average boiling points of the liquid and vapor are +30° and −120° F., respectively. The fugacity coefficients of liquid and vapor, read from the chart, are 3700 and 1200, respectively. The K-value is the ratio of these two numbers, or 3.08.

Figures 10-12 are divided into two parts to prevent overlapping of lines, because the fugacity coefficient passes through a minimum with respect to molal average boiling point near the boiling point of the pure component. Otherwise, these charts are similar to that for methane, and are used in the same way.

These charts illustrate the large variation of fugacity coefficients with composition, here represented by molal average boiling point. The effect of composition becomes smaller as the molal average boiling point of the pure component is approached.

3.2 Use of Charts to Calculate Dew and Bubble Points. The principal practical uses of these charts of fugacity coefficients and K-values are for calculation of dew points, bubble points and equilibrium flash separations. Use of the present charts for these calculations proceeds by successive approximation, as is the case when these calculations are made with the familiar K-charts. A complication is introduced by the present charts: because of the dependence of fugacity coefficients on composition, it is necessary to satisfy two conditions in these successive approximations, rather than the single condition to be satisfied when K-charts independent of composition are used.

In calculating dew or bubble points with these charts it is necessary to assume a trial value for the pressure or temperature sought and a molal average boiling point for the phase whose composition is not given. The two conditions to be satisfied then are: (1) that the sum of mole fractions of the phase whose composition is not

Publication of this paper was started in the August, 1951, issue, continued in September and November, and concluded with this issue.

Complete data for Tables 1-4 and 6-8 are on file (Document 3359) with the American Documentation Institute, 1719 N Street, Northwest, Washington, D. C. Obtainable by remitting $1.20 for microfilm and $1.00 for photocopies.

† Present address: Mass. Inst. Technology, Cambridge, Mass.

‡ Present address: Foster Wheeler Corp., New York, N. Y.

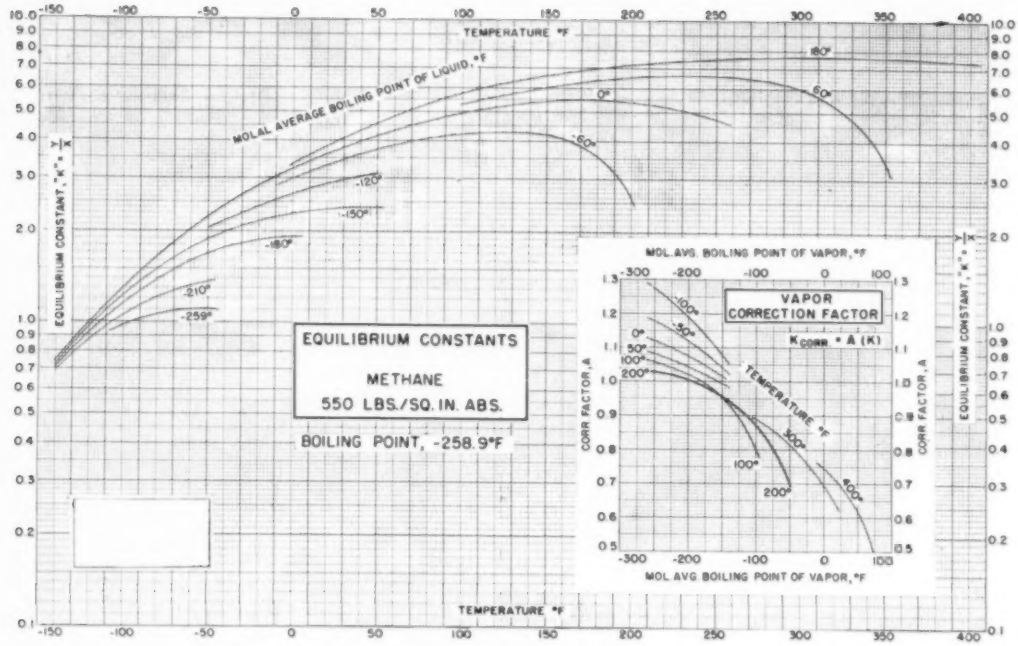


Fig. 5. K-value of methane at 550 lbs./sq.in. abs.

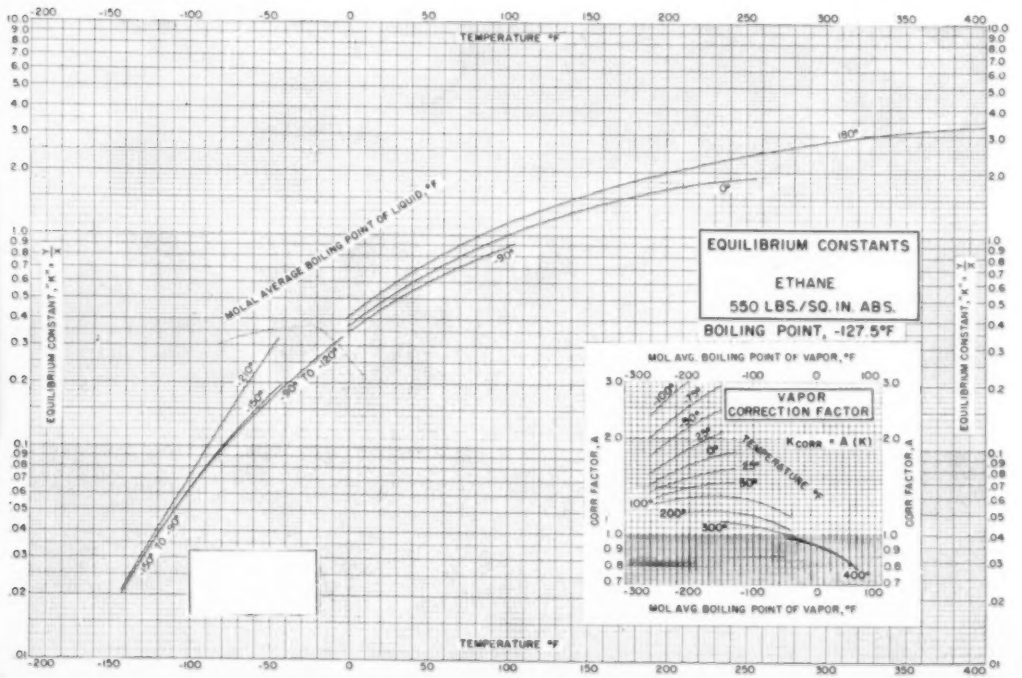


Fig. 6. K-value of ethane at 550 lbs./sq.in. abs.

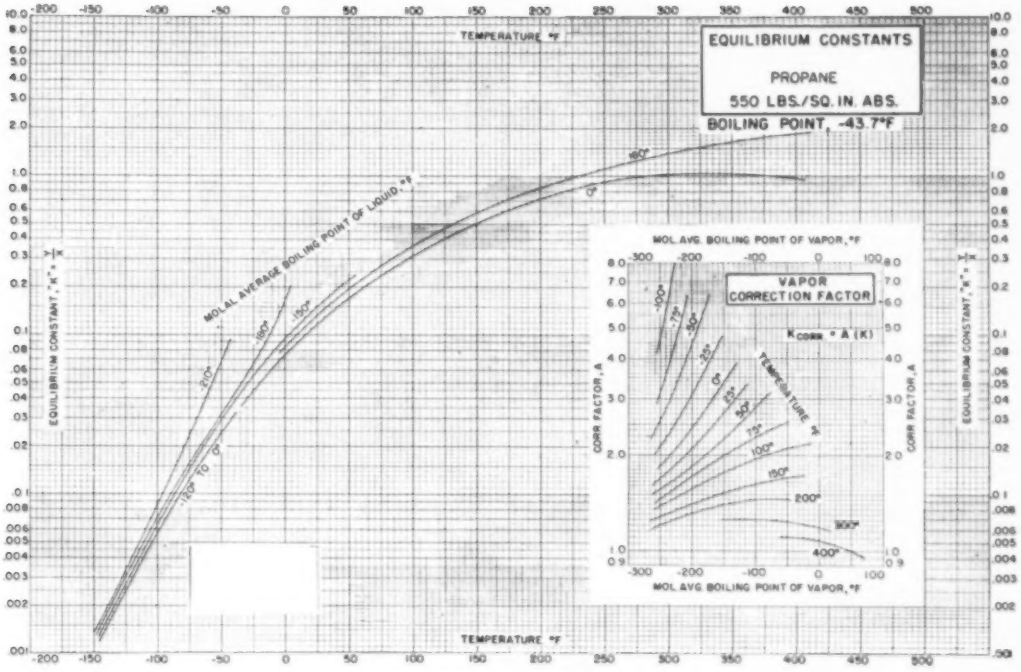


Fig. 7. K-value of propane at 550 lbs./sq.in. abs.

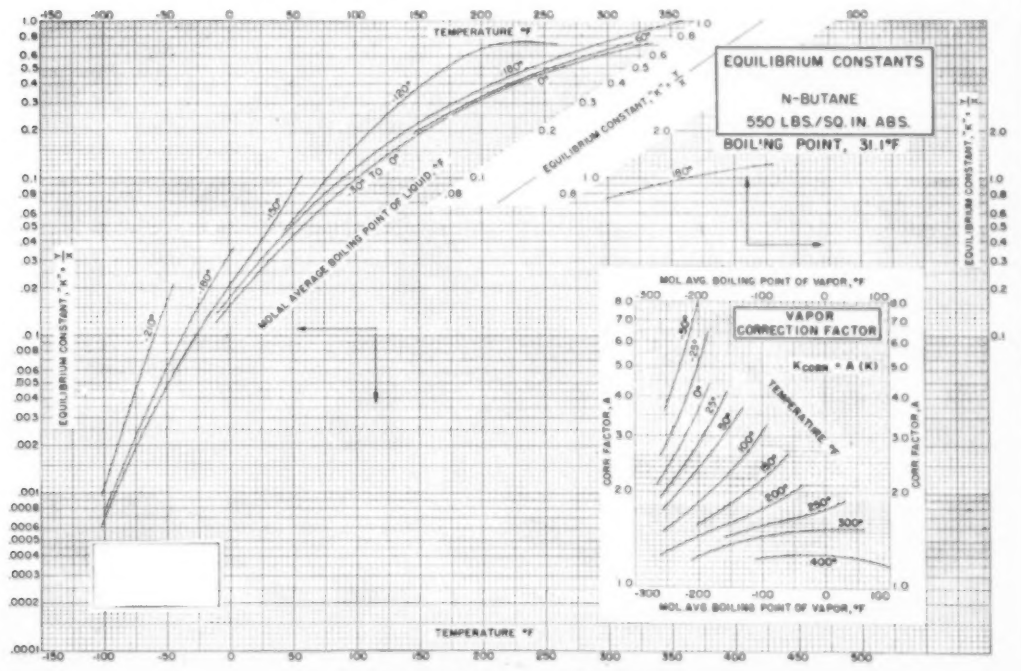


Fig. 8. K-value of n-butane at 550 lbs./sq.in. abs.

TABLE 9.—FUGACITY FUNCTIONS OF METHANE AT 100° F.

Molal Average B.P.—° F.

Phase	Pressure lbs./sq.in.abs.	−240	−210	−180	−150	−120	−90	−60	−30	0	30	60	90	120	150	180	Pressure lbs./sq.in.abs.
								f/Py									
V	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000							0
V	50	0.996	0.997	0.999	1.002	1.005	1.014	1.021	1.031	1.046	1.062						50
V	100	0.991	0.994	0.998	1.007	1.020	1.029	1.043	1.068	1.100							100
V	200	0.982	0.988	0.997	1.014	1.040	1.067	1.109	1.17								200
V	400	0.964	0.975	0.997	1.030	1.097	1.188										400
V	600	0.946	0.962	1.002	1.055	1.226											600
V	800	0.929	0.951	1.017	1.103												800
								f/x lbs. sq.in.abs.									
										2456	2564	2656	2745	2816	2870	2907	
L	0							2179	2399	2549	2658	2752	2837	2907	2961	2994	0
L	200						1980	2281	2495	2644	2755	2850	2931	2999	3053	3090	200
L	400						2090	2383	2596	2743	2855	2959	3032	3097	3151	3188	400
L	800						2204	2490	2702	2850	2960	3065	3135	3200	3254		800
L or V	1000	912	941	1017	1175	1910	2322	2603	2811	2959	3070	3165	3243	3308			1000
L or V	1200	1076	1118	1240	1532	2092	2435	2716	2926	3079	3191	3288	3366	3422			1200
L or V	1400	1235	1292	1430	1845	2330	2572	2836	3042	3195	3311	3406	3471				1400
L or V	1600	1390	1463	1620	2155	2568	2708	2956	3162	3303	3418	3511	3589				1600
L or V	1800	1540	1631	1822	2210	2249	2850	3083	3286	3425	3539	3611					1800
L or V	2000	1687	1796	1995	2357	2698	2971	3210	3430	3540	3642						2000
L or V	2200	1831	1958	2169	2538	2846	3106	3338	3536	3675							2200
L or V	2400	1972	2117	2346	2692	2993	3243	3467	3662	3790							2400
L or V	2600	2112	2272	2517	2843	3140	3381	3594	3784	3928							2600
L or V	2800	2251	2425	2682	2992	3287	3520	3731	3916	4056							2800
L or V	3000	2390	2575	2843	3149	3432	3660	3868	4045								3000
L or V	3200	2528	2721	3000	3285	3575	3803	4005									3200
L or V	3400	2665	2864	3152	3429	3718	3942	4139									3400
L or V	3600	2800	3006	3300	3570	3860	4084										3600

given is unity, and (*2*) that the molal average boiling point calculated for the phase whose composition is not given equals that assumed for the trial value.

A systematic procedure for calculating dew or bubble points by means of these charts is illustrated by the sample calculation of bubble-point temperature which follows. A tabular form for carrying out this calculation is illustrated in Table 10. In this example the quantities given are the liquid mole fractions

Methane	0.30
Ethane	0.10
Propane	0.25
n-Butane	0.35

and the pressure, 1000 lb./sq.in.abs. The quantities to be calculated are the bubble-point temperature and the composition of the vapor.

Part 1 of Table 10 lists the given data and shows the calculation of the molal average boiling point of the given liquid (B_L), in this case −90.4° F. Part *2* of this table lists the values assumed for the temperature and molal average boiling point of the vapor to start each trial calculation. Part 3 of this table shows the steps in the successive trial calculations. First, fugacity coefficients for each phase are read from the charts (in this case, Figs. 9-12) at the appropriate pressure, temperature and molal average boiling point. Then, K's are evaluated as the ratio of fugacity coefficients. Next, the vapor mole fractions are calculated as $K_i x_i$. Finally, the molal average boiling point of the vapor is evaluated.

In the first trial of Table 10, the sum of the vapor mole fractions is 1.028 instead of 1.000. This indicates that a temperature lower than 120° F. assumed in the first trial should be used in the second trial; 100° F. is selected. The vapor molal average boiling point calculated in the first trial is −197.9° F. instead of −210° F., as assumed. This calculated value could have been used in the second trial, but experience has shown that the calculation sometimes converges more rapidly if the value chosen is stepped ahead, so −190° F. is used in the second trial.

By proceeding in this way through three trials it is found that an assumed temperature of 104° F. and an assumed vapor molal average boiling point of −198° F. results in $\sum y_i = 1.000$, and a calculated molal average boiling point of −199.4° F. Since this is an adequate check, the temperature of 104° F. may be accepted as the required dew point, and the values of y_i given for the third trial may be taken as the composition of the vapor at this point.

Analogous procedures are used to calculate bubble-point pressures or dew-point pressures or temperatures.

3.3 Use of Charts to Calculate Equilibrium Flash Separations. In calculating

an equilibrium flash separation by means of these charts it is necessary to assume trial values of (1) the ratio of the number of moles of liquid to the number of moles of vapor (L/G), and (2) the molal average boiling point of one of these phases. The molal average boiling point of the other phase may be obtained from the molal average boiling of the feed to the separation, B, by the relation

$$\frac{B_L L/G + B_G}{L/G + 1} = B \qquad (5)$$

The two conditions which are satisfied when the correct assumptions have been made are: (1) the calculated value of L/G equals the assumed value, and (2) the molal average boiling point calculated for one of the phases equals the assumed value.

Table 11 illustrates a systematic procedure for calculating equilibrium flash separations by means of these charts. In this example the quantities given are the pressure, 1000 lb./sq.in.abs.; the temperature, 100° F.; and the number of moles of individual components in the feed: Methane, 40; ethane, 10; propane, 20; and *n*-butane, 30. The quantities to be calculated are the number of moles of each component in the vapor and liquid phases in equilibrium under these conditions.

Part 1 of Table 11 lists the given data and shows the calculation of the molal average boiling point of the given feed, (B), in this case −115.76° F. Part 2 of this table lists the values assumed for L/G and the molal average boiling point of the vapor (B_G) in three successive trial calculations. Calculation of the molal average boiling point of the liquid (B_L) from B and B_G in each trial is also illustrated. The boiling point of the phase present in smaller amount (in this case the vapor) should be assumed, and the boiling point of the other phase calculated from it.

Part 3 of this table shows the steps in the successive trial calculations. First, fugacity coefficients are read from the charts and K's are evaluated from them. Next, the number of moles of each component in the vapor, g_i, is calculated by the equation given in the table. Then, L/G is evaluated and compared with the value assumed, and finally, the molal average boiling point of the vapor is calculated and compared with the value assumed.

If desired, the value of L/G and B_G evaluated in one trial may be used as assumed values in the succeeding trial. Experience, however, has shown that the trials converge more rapidly if the values assumed for the next trial are stepped ahead of the values calculated in the preceding one. After three trials in Table 11 the calculation has converged satisfactorily, with a calculated L/G of 3.48 matching an assumed value of 3.50, and a calculated B_G of −202.8 matching an assumed value of −202.0° F.

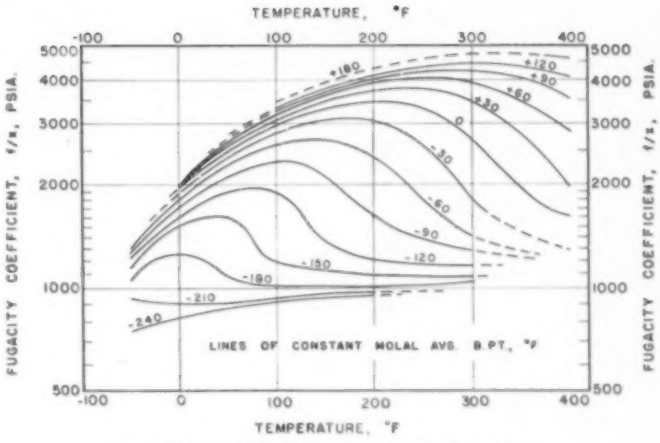


Fig. 9. Fugacity coefficient of methane at 1000 lbs./sq.in. abs.

4. Comparison of Charts with Equations and Experimental Data

Before these charts may be used with confidence, it is important to show that K's obtained from them are in agreement with those calculated by the equations, particularly for systems different from the binary mixtures of normal paraffins for which the charts were calculated. It is even more important to establish that K's read from the charts are in satisfactory agreement with experimental determinations of K. These two comparisons are made in this section.

4.1 Methane-Ethylene-Isobutane System. The methane-ethylene-isobutane system, investigated experimentally by Benedict, Solomon and Rubin (*1*), provides an especially valuable check of the charts against the equation and against experimental data, because two of the components, ethylene and isobutane,

TABLE 10.—SAMPLE CALCULATION OF BUBBLE-POINT TEMPERATURE

1. Given					2. Trial Assumptions		3. Check of Assumptions						
							Fugacity Coeff.						
Component	B.P., °F. B_i	Liquid Mole Fraction x_i	x_iB_i	Pressure lb./sq.in.abs.	Temp., °F.	Vapor Mole Avg. B.P., °F. B_G	Liquid $f^{0'}/x_i$	Vapor $f^{0''}/x_i$	$K_i = \frac{f^{0'}/x_i}{f^{0''}/x_i}$	Vapor Mole Fract. $y_i = Kx_i$	y_iB_i	$B_G = \Sigma y_iB_i/\Sigma y_i$	
C_1	−258.9	0.30	−77.7				2310	950	2.432	0.730	−189.0		
C_2+	−127.5	0.10	−12.7				618	660	0.936	0.094	−11.9		
C_3+	−43.7	0.25	−10.9				241	505	0.477	0.119	−5.2		
n−C_4+	+31.1	0.35	+10.9				92	380	0.242	0.085	+2.6		
Σ		1.00	−90.4	1000	120	−210				1.028	−203.5	−197.9	
C_1	−258.9	0.30					2310	985	2.345	0.704	−182.3		
C_2+	−127.5	0.10					552	605	0.912	0.091	−11.6		
C_3+	−43.7	0.25					190	409	0.465	0.116	−5.1		
n−C_4+	+31.1	0.35					69.5	290	0.240	0.084	+2.6		
Σ		1.00	−90.4	1000	100	−190				0.995	−196.4	−197.3	
C_1	−258.9	0.30					2310	968	2.386	0.716	−185.4		
C_2+	−127.5	0.10					563	625	0.901	0.090	−11.5		
C_3+	−43.7	0.25					200	438	0.457	0.114	−5.0		
n−C_4+	+31.1	0.35					73	318	0.230	0.080	+2.5		
Σ		1.00	−90.4	1000	104	−198				1.000	−199.4	−199.4	

TABLE 11.—SAMPLE CALCULATION OF EQUILIBRIUM FLASH SEPARATION.

	1. Given			2. Trial Assumptions			3. Check of Assumptions							
Component	B.P., °F. B_i	Moles in Feed f_i	f_iB_i	L/G	Vapor Mole Avg. B.P., °F. B_a	Liquid Mole Avg. B.P., °F. $B_L = B\left(\frac{L}{G}+1\right) - Ba$ / L/G	Fugacity Coeff. Liquid f_i^L/x_i	Fugacity Coeff. Vapor f_i^G/x_i	$K_i = \frac{f_i^L/x_i}{f_i^G/x_i}$	$L/G\ K_i$	Moles in Vapor $g_i = \frac{f_i}{1+L/GK_i}$	g_iB_i	Vapor Mole Avg. B.P., °F. $Ba = \Sigma g_iB_i/\Sigma g_i$
C_3	−258.9	40	−10,360				2305	940	2.451	1.55	15.69	−4062	
C_2	−127.5	10	−1,275				552	628	0.879	4.328	1.876	−239	
C_3	−43.7	20	−874				191	458	0.417	9.120	1.977	−86	
C_4	+31.1	30	933				69	330	0.2091	8.16	1.565	+49	
Σ		100	−11,576	3.8*	−210	−90.9					21.108	−4338	−205.5
		$B = \Sigma f_iB_i/\Sigma f_i = -115.76$									$L/G = (\Sigma f_i/\Sigma g_i) - 1 = 3.73^*$		
C_3	−258.9	40					2320	950	2.44	1.476	16.20	−4190	
C_2	−127.5	10					552	620	0.890	4.04	1.981	−253	
C_3	−43.7	20					190	443	0.428	8.41	2.124	−93	
C_4	+31.1	30					69	320	0.215	16.74	1.792	+56	
Σ		100		3.6**	−205	−88.1					22.097	−4480	−202.2
		$B = -115.76$									$L/G = 3.53^{**}$		
C_3	−258.9	40					2320	955	2.43	1.44	16.39	−4240	
C_2	−127.5	10					552	618	0.893	3.92	2.034	−259	
C_3	−43.7	20					190	440	0.431	8.22	2.165	−95	
C_4	+31.1	30					69	742	0.221	15.83	1.783	+56	
Σ		100		3.5***	−202	−87.7					22.372	−4538	−202.8
		$B = -115.76$									$L/G = 3.48^{***}$		

were not present in the mixtures from which the charts were calculated. Table 12 lists the equilibrium states observed experimentally for this system and compares the K's observed with K's read from the charts and evaluated from the equations. In addition to providing this comparison for the three components actually present in the mixture, K's for the two additional components, propane and *n*-pentane, considered present at limiting mole fractions of zero, have been read from the charts and calculated by the equations for these equilibrium states.

The average absolute deviation of chart K's from K's calculated by the equations ranges from only 1.3% for isobutane to 2.8% for methane. The maximum departure at any point is +8.4% for *n*-pentane. This is considered to be a satisfactory check of the consistency of charts and equation for this system.

In comparing the K's read from the charts with observed K's, the absolute average deviations are 3.8% for methane, 2.1% for ethylene and 1.6% for isobutane. The corresponding deviations of K's calculated by the equations from

TABLE 12.—METHANE COMPARISON OF CHART K's WITH

Temperature, °F.	100	100	100	100	100	100	100	100
Pressure, lb./sq.in. gage	500.7	500	500	500	1000	1000	1000	1000
Mole Fract. in Vapor								
Methane	0.5765	0.3355	0.1875	.....	0.657	0.552	0.434	0.3575
Ethylene	0.224	0.4815	0.640	0.8505	0.187	0.297	0.4205	0.500
Isobutane	0.1995	0.183	0.1725	0.1595	0.156	0.151	0.1465	0.1425
Mole Fract. in Liquid								
Methane	0.1235	0.069	0.039	.....	0.284	0.252	0.2155	0.189
Ethylene	0.1245	0.279	0.372	0.497	0.1705	0.270	0.3835	0.462
Isobutane	0.752	0.652	0.589	0.503	0.5455	0.478	0.401	0.349
Mole Avg. B.P., °F.								
Vapor	−181.7	−159.3	−145.7	−128.3	−197.3	−187.2	−175.8	−168.3
Liquid	−43.0	−53.9	−61.2	−71.4	−94.0	−101.8	−110.7	−116.6
K, Methane								
Observed	4.67	4.86	4.8	.....	2.31	2.19	2.01	1.89
Equation	4.89	4.59	4.46	4.14	2.35	2.21	2.02	1.88
Charts	4.88	4.59	4.42	4.12	2.33	2.16	1.96	1.81
K, Ethylene								
Observed	1.80	1.73	1.72	1.69	1.10	1.10	1.10	1.08
Equation	1.77	1.74	1.72	1.67	1.12	1.11	1.10	1.09
Charts	1.75	1.70	1.67	1.62	1.10	1.11	1.09	1.08
K, Isobutane								
Observed	0.265	0.281	0.293	0.317	0.286	0.316	0.363	0.408
Equation	0.269	0.288	0.303	0.326	0.287	0.320	0.370	0.417
Charts	0.268	0.284	0.300	0.315	0.284	0.319	0.373	0.417
K, Propane								
Equation	0.519	0.538	0.552	0.572	0.456	0.488	0.534	0.575
Charts	0.519	0.543	0.559	0.580	0.462	0.500	0.554	0.590
K, n-Pentane								
Equation	0.0897	0.101	0.111	0.126	0.130	0.155	0.191	0.239
Charts	0.0842	0.101	0.113	0.130	0.125	0.1528	0.1923	0.235
Per Cent Deviation in Chart K's from Equation 100 (Equation-Charts)/Obs.								
Methane	−0.2	±0.0	+0.8	+0.5	+0.9	+2.3	+3.0	+3.7
Ethylene	+1.1	+2.3	+2.9	+3.0	+1.8	±0.0	+0.9	+0.9
Isobutane	+0.4	+1.3	+1.0	+3.5	+1.0	+0.3	−0.8	±0.0
Propane	±0.0	−0.9	−1.3	−1.4	−1.3	−2.5	−3.7	−2.6
n-Pentane	+6.1	±0.0	−1.8	−3.2	+3.8	+1.4	−0.7	+1.7
Per Cent Deviation in Chart K's from Obs. K's 100 (Obs.-Charts)/Obs.								
Methane	−4.5	+5.5	+7.9	.....	−0.9	+1.4	+2.5	+4.2
Ethylene	+2.8	+1.7	+2.9	+4.1	±0.0	−0.9	+0.9	±0.0
Isobutane	−1.2	−1.1	−2.4	+0.6	+0.7	−0.9	−2.8	−2.3

TABLE 13.—SUMMARIZED COMPARISON OF K's EVALUATED BY EQUATION WITH K's READ FROM CHARTS

System	Average Per Cent Deviation in K								
	C_1	C_2—	C_2	C_3	i — C_4	n — C_4	n — C_5	n — C_7	
Methane-Ethylene-Isobutane	2.8	2.1	...	1.2	1.8	...	2.5	...	
Methane-Ethane-n-Pentane	2.3	...	1.0	...	...	...	7.2	...	
Methane-Propane	2.5	...	...	2.0	...	...	...	...	
Methane-Propane-Pentane	2.0	...	...	1.9	...	...	3.2	...	
Methane-Isobutane	2.0	...	...	...	1.2	...	...	...	
Methane-n-Butane	2.3	...	...	...	...	1.5	...	...	
Methane-n-Pentane	2.2	...	...	...	...	...	1.2	...	
Ethylene-n-Heptane	...	4.2	...	...	...	...	...	16.4	
Ethane-n-Butane	...	...	2.0	...	...	5.2	...	...	
Ethane-n-Heptane	...	...	3.8	...	...	...	...	9.2	Over-all Average
Propane-n-Pentane	...	...	...	1.1	...	...	2.8	...	3.2
n-Butane-n-Heptane	...	...	...	...	...	1.3	...	3.5	
ALL SYSTEMS	2.3	3.2	2.3	1.6	1.5	2.7	3.4	9.7	

observed K's for this system, reported in the preceding paper (*5*) were 2.3% for methane, 1.1% for ethane and 1.5% for isobutane. Although the deviations of the charts from observed K's are greater than the equations, the charts still provide a very satisfactory representation of the experimental data for this system. This is the more noteworthy when it is remembered that two components of this system, ethylene and isobutane, were not used in the mixtures from which the charts were calculated.

4.2 Summarized Comparison of Charts with Equations. Table 13 summarizes a comparison which has been made between K's read from the charts and K's calculated by the equation at all of the equilibrium states observed for the 12 selected investigations reported in the preceding paper of this series (*5*). Except for K's for n-heptane, the average difference between K's read from the charts and K's calculated by the equations is 5% or less. It has been noted that this is the order of magnitude of the scatter of the individual fugacity coefficients from the smooth curves put through the calculated points in preparing these charts.

The over-all absolute average deviation of charts from equations is only 3.2%. This is an indication of the close agreement of these charts with the fugacity coefficient equations.

4.3 Summarized Comparison of Charts with Observed K's for Twelve Selected Systems. A comparison between K's read from the charts and K's observed at the equilibrium states for these 12 selected investigations reported in the preceding paper of this series (*5*) is summarized in Part 1 of Table 14. The average deviations are less than 5% for all components except *n*-pentane and *n*-heptane. The over-all average deviation is 4.7%. Although this deviation is probably somewhat greater than the experimental uncertainty in these selected investigations, the chart K's still agree well enough with the observed K's for engineering purposes.

4.4 Additional Measurements Compared with Charts. In addition to the 12 systems listed in Part 1 of Table 14, a number of other investigations have been made of liquid-vapor equilibria in mixtures of light hydrocarbons. Most of these other investigations are compared with the charts in Part 2 of this table. Although many of these are of lower precision than the 12 systems of Part 1, it is important to compare them with the charts, because in many cases the mixtures studied are more representative of those encountered in petroleum engineering than the simple mixtures of two and three components treated in Part 1. The average devia-

—ETHYLENE—ISOBUTANE SYSTEM

OBSERVED EQUILIBRIA (*1*) AND EQUATION

100 1000	160 500	160 500	160 500	160 500	160 1000	160 1000	160 1000		
0.257	0.418	0.269	0.148	.....	0.459	0.263	0.1625		
0.6035	0.1635	0.3255	0.4585	0.624	0.2295	0.408	0.5175		
0.1395	0.4185	0.4055	0.3935	0.576	0.3115	0.309	0.320		
0.1575	0.083	0.0565	0.030	.....	0.2175	0.159	0.1135		
0.563	0.078	0.150	0.215	0.296	0.181	0.334	0.4585		
0.2795	0.839	0.7935	0.755	0.704	0.6015	0.507	0.428		
— 158.4	— 129.0	— 115.6	— 104.9	— 92.4	— 150.9	— 133.0	— 118.6		
— 124.8	— 24.4	— 29.2	— 32.8	— 38.1	— 77.8	— 87.3	— 95.6		
1.63	5.04	4.76	4.90	.....	2.11	1.78	1.43		
1.67	5.03	4.84	4.68	4.44	2.15	1.79	1.43		
1.58	4.96	4.71	4.54	4.23	2.05	1.68	1.35		
1.07	2.10	2.17	2.13	2.11	1.27	1.22	1.13		
1.07	2.23	2.20	2.16	2.10	1.29	1.22	1.13		
1.06	2.20	2.12	2.07	2.02	1.24	1.20	1.14		
0.499	0.499	0.511	0.521	0.534	0.518	0.609	0.748		
0.513	0.503	0.516	0.528	0.544	0.518	0.615	0.749		
0.516	0.487	0.505	0.519	0.534	0.521	0.628	0.770		
0.854	0.848	0.856	0.862	0.870	0.709	0.776	0.860		
0.678	0.832	0.841	0.856	0.861	0.723	0.793	0.872		
0.336	0.218	0.230	0.240	0.255	0.310	0.420	0.597		
0.339	0.214	0.229	0.242	0.261	0.284	0.406	0.620		
								Avg. Alg.	Dev. Abs.
+ 5.5	+ 1.4	+ 2.7	+ 2.9	+ 4.8	+ 4.7	+ 6.2	+ 5.6	+ 3.8	3.8
+ 0.9	+ 1.4	+ 3.7	+ 4.2	+ 3.8	+ 3.9	+ 1.7	— 0.9	+ 2.0	2.1
— 0.6	+ 1.2	+ 2.1	+ 1.7	+ 1.9	— 0.6	— 2.0	— 2.6	+ 0.5	1.3
— 3.7	+ 1.9	+ 1.8	+ 0.7	+ 1.0	— 2.0	— 2.2	— 1.4	— 1.1	1.8
— 0.9	+ 1.8	+ 0.4	— 0.8	— 2.0	+ 8.4	+ 3.3	+ 3.9	+ 1.3	2.5
+ 3.1	+ 1.6	+ 1.1	+ 7.3	.....	+ 2.8	+ 5.6	+ 5.5	+ 3.1	3.8
+ 0.9	— 4.8	+ 2.3	+ 2.6	+ 4.3	+ 2.4	+ 1.6	— 0.9	+ 1.3	2.1
— 3.4	+ 2.4	+ 1.2	+ 0.4	± 0.0	— 0.6	— 3.1	— 2.9	— 1.0	1.6

TABLE 14.—SUMMARIZED COMPARISON OF OBSERVED *K*'s OF LIGHT HYDROCARBONS WITH THOSE READ FROM CHARTS

System	Literature Cited	Pressure lb./sq.in.abs.	Temperature °F.	Average Per Cent Deviation in *K* Value												
				C_1	C_2	C_3	C_4	C_5	$i-C_4$	$i-C_5$	$n-C_4$	$i-C_5$	$n-C_5$	$n-C_6$	$n-C_7$	
Part 1. Selected Investigations																
Methane-Ethylene-Isobutane	1	500-1000	100-160	3.8	2.1	...	...	1.6	...	...	...	...	...	...	...	
Methane-Ethane-n-Pentane	6	500-2000	100	1.2	...	1.8	...	...	...	...	...	...	5.9	...	...	
Methane-Propane	27	441-1323	68-131	6.7	...	...	3.3	...	...	...	...	...	...	...	...	
Methane-Propane-n-Pentane	7, 10	500-2000	100-220	2.9	...	...	4.9	...	...	...	...	...	9.7	...	...	
Methane-Isobutane	21	500-1396	100-220	4.9	...	...	...	1.8	...	...	...	...	...	...	...	
Methane-n-Butane	25	400-1600	70-250	3.1	...	...	...	...	...	...	3.4	...	...	...	...	
Methane-n-Pentane	31	600-2000	100-220	3.4	...	...	...	...	...	...	...	...	8.2	...	...	
Ethylene-n-Heptane	18	400-1000	185-350	...	3.2	...	...	...	...	...	...	...	...	...	12.5	
Ethane-n-Butane	16	200- 800	26-265	...	...	2.3	...	...	...	...	5.9	...	...	...	...	
Ethane-n-Heptane	15	400-1000	185-350	...	...	2.1	...	...	...	...	...	...	...	...	8.9	
Propane-n-Pentane	26	300- 500	190-340	...	...	...	4.1	...	...	...	...	...	5.8	...	...	
n-Butane-n-Heptane	17	65- 480	200-400	...	...	...	...	...	...	...	3.6	...	...	...	9.2	Over-all Avg.
AVERAGE, ALL SELECTED SYSTEMS				3.7	2.6	2.1	4.1	1.7	...	...	4.3	...	7.4	...	10.2	4.7
Part 2. Other Investigations																
Five-Component Systems	13	517-1822	100	2.3	...	5.4	...	6.7	...	...	13.5	...	9.9	3.3	...	
Methane-n-Hexane	28	655-2528	100-220	3.5	...	...	...	...	...	...	...	...	...	...	...	
Methane-Cyclohexane	28	2045-2734	100-220	13.2	...	...	...	...	...	...	...	...	...	...	...	
Methane-Benzene	28	1448-2390	100-220	(39)	...	...	...	...	...	...	...	...	...	...	...	
Methane-n-Decane	19	1000-2000	100-220	2.6	...	...	...	...	...	...	...	...	...	...	...	
Natural Gas-Distillate	23	293-3485	40-200	7.1	...	7.1	...	5.9	...	...	...	...	...	...	...	
Absorption Oil	33	500-2000	100	7.7	...	16	...	7.5	11	...	17.1	11.9	12	6.9	...	
Methane-Ethylene	32, 12	140- 882	−108- 32	30	10	...	...	...	...	...	...	...	...	...	...	
Methane-Ethylene-Ethane	12	294- 735	−108- 32	14	18	12	...	...	...	...	...	...	...	...	...	
Methane-Ethane	12, 24	147-1176	−108- 32	17	...	7.4	...	...	...	...	...	...	...	...	...	
Ethylene-Ethane	22	208- 694	−14- 74	...	4.9	4.0	...	...	...	...	...	...	...	...	...	
Propylene-Isobutane	11	200- 600	108-249	...	...	...	2.5	...	7.4	...	...	...	...	...	...	
Propane-Isobutylene	29	200- 600	130-263	...	...	...	...	7.1	...	4.6	...	...	...	...	...	
Propane-n-Butane	20	200- 500	130-280	...	...	...	...	9.3	...	...	8.1	...	...	...	...	
n-Butane-n-Hexane	8	147- 492	218-379	...	...	...	...	...	...	...	2.2	...	...	7.0	...	Over-all Avg.
n-Pentane-n-Heptane	9	147- 444	287-407	...	...	...	...	...	...	...	...	...	2.5	...	3.3	
AVERAGE, ALL SYSTEMS				7.7	7.6	6.5	2.5	6.4	6.0	4.6	7.7	11.9	7.7	5.7	8.5	7.1

TABLE 15.—TWO FIVE-COMPONENT SYSTEMS AT 100° F. (*11*) — COMPARISON OF OBSERVED *K*'s WITH CHARTS

Pressure, lb./sq.in.abs.	1046	1235	1419	1639	1822	517	946	1297	1431	1736		
Mole Fraction in Vapor												
Methane	0.7801	0.8040	0.7645	0.7853	0.7647	0.8398	0.8543	0.8561	0.8442	0.8270		
Ethane	0.1102	0.1039	0.1169	0.1022	0.1022	0.0663	0.0627	0.0615	0.0656	0.0609		
Propane	0.0787	0.0700	0.0836	0.0764	0.0779	0.0531	0.0487	0.0477	0.0285	0.0288		
n-Butane	.....	.....	.....	.....	.....	0.0267	0.0161	0.0215	0.0207	0.0279		
n-Pentane	0.0223	0.0140	0.0215	0.0198	0.0309	0.0341	0.0382	0.0332	0.0410	0.0554		
n-Hexane	0.0087	0.0081	0.0135	0.0163	0.0243	.....	.....	.....	.....	.....		
Mole Fraction in Liquid												
Methane	0.3042	0.3472	0.3858	0.4512	0.5574	0.1479	0.2866	0.3828	0.4199	0.5251		
Ethane	0.1311	0.1325	0.1314	0.1308	0.1222	0.0438	0.0718	0.0756	0.0752	0.0727		
Propane	0.2026	0.1893	0.1755	0.1490	0.1369	0.0814	0.0780	0.0705	0.0681	0.0595		
n-Butane	.....	.....	.....	.....	.....	0.1522	0.1323	0.1329	0.1055	0.0846		
n-Pentane	0.2021	0.1613	0.1449	0.1256	0.0851	0.5747	0.4313	0.3572	0.3313	0.2585		
n-Hexane	0.1600	0.1697	0.1624	0.1434	0.0984	.....	.....	.....	.....	.....		
Molal Avg. B.P., °F.												
Vapor	−215.8	−221.8	−212.3	−215.2	−207.6	−223.3	−226.3	−226.7	−223.7	−216.9		
Liquid	−59.8	−73.0	−85.1	−105.5	−142.4	+12.93	−40.90	−74.02	−85.9	−120.3		
K, Observed												
Methane	2.564	2.316	1.982	1.740	1.372	5.678	2.981	2.231	2.010	1.575		
Ethane	0.841	0.784	0.890	0.781	0.836	1.514	0.873	0.813	0.872	0.858		
Propane	0.388	0.370	0.476	0.513	0.569	0.407	0.368	0.393	0.419	0.482		
n-Butane	.....	.....	.....	.....	.....	0.175	0.122	0.190	0.196	0.332		
n-Pentane	0.110	0.087	0.148	0.158	0.363	0.059	0.089	0.093	0.124	0.214		
n-Hexane	0.054	0.048	0.083	0.114	0.247	.....	.....	.....	.....	.....		
Per Cent Deviation in *K*, 100(Obs.-Chart)/Obs.											Avg. Alg.	Dev. Abs.
Methane	−5.9	−0.4	−2.5	−0.2	−1.2	+2.3	+4.4	−1.8	−2.0	−1.9	−0.9	2.3
Ethane	−5.4	−6.5	+4.6	−7.0	−3.5	+13.1	−5.4	−0.1	+7.2	+1.8	−0.2	5.4
Propane	−3.4	−9.7	+1.5	+2.9	−10.7	−20.9	−8.7	−1.5	−1.2	−6.4	−5.8	6.7
n-Butane	.....	.....	.....	.....	.....	−2.3	−44.3	−3.7	−13.3	+3.9	−11.5	13.5
n-Pentane	+18.3	−13.2	+3.4	−17.1	+0.5	−13.6	+16.9	−4.3	+8.1	+3.7	+0.3	9.9
n-Hexane	+16.7	−9.0	−1.2	−1.8	−4.5	.....	.....	.....	.....	.....	±0.0	3.3

TABLE 16.—METHANE-n-HEXANE, METHANE-CYCLOHEXANE, METHANE-BENZENE AND METHANE-n-DECANE SYSTEMS

System	Temp., °F	Press., lb./sq.in.abs.	Mole Fract. Methane		Mole Avg. B.P.		K (Obs.) Methane	100[K (Obs.) —K (Chart)] / K (Obs.)
			Vapor	Liquid	Vapor	Liquid		
Methane-n-Hexane (20)	100	655	0.98	0.192	−250.6	+76.1	5.10	+0.8
	100	1623	0.97	0.430	−246.4	−22.6	2.25	−3.1
	100	2412	0.96	0.561	−242.3	−76.8	1.71	0.0
	160	739	0.95	0.192	−238.2	+76.1	4.94	−2.0
	160	1775	0.94	0.430	−234.1	−22.6	2.19	−5.0
	160	2528	0.92	0.561	−235.7	−76.8	1.64	−0.4
	220	795	0.89	0.192	−213.3	+76.1	4.63	−10.4
	220	1855	0.88	0.430	−209.1	−22.6	2.05	−5.9
	220	2508	0.82	0.561	−184.3	−76.8	1.46	−4.0
							Alg. Avg.	−3.3
							Abs. Avg.	3.5
Methane-Cyclohexane (18)	100	2045	0.98	0.368	−250.2	+16.8	2.66	+18.6
	100	2568	0.96	0.449	−241.4	−18.5	2.13	+14.2
	160	2196	0.95	0.368	−237.1	+16.8	2.58	+17.3
	160	2698	0.94	0.449	−232.8	−18.5	2.09	+8.8
	220	2240	0.91	0.368	−219.6	+16.8	2.47	+12.3
	220	2734	0.88	0.449	−206.5	−18.5	1.96	+8.0
							Alg. Avg.	+13.2
							Abs. Avg.	13.2
Methane-Benzene (26)	100	1448	0.98	0.180	−250.2	+98.2	5.44	+48
	100	2390	0.98	0.286	−250.2	+52.0	3.43	+43
	160	1456	0.96	0.180	−242.4	+98.2	5.33	+42
	160	2354	0.95	0.286	−238.2	+52.0	3.32	+35
	220	1432	0.93	0.180	−228.4	+98.2	5.17	+38
	220	2310	0.91	0.286	−219.7	+52.0	3.18	+27
							Alg. Avg.	+39
							Abs. Avg.	39
Methane-n-Decane (19)	100	1000	0.9996	0.2596	−258.7	189.4	3.88	−0.3
	100	1500	0.9994	0.3489	−258.5	134.3	2.86	+1.4
	100	2000	0.9990	0.4379	−258.3	80.6	2.28	−0.9
	160	1000	0.9988	0.2387	−258.2	200.9	4.19	−4.5
	160	1500	0.9983	0.3240	−257.9	149.4	3.08	+1.0
	160	2000	0.9976	0.4087	−257.5	98.2	2.44	−2.9
	220	1000	0.9970	0.2288	−257.1	210.5	4.47	−6.5
	220	1500	0.9952	0.3064	−256.0	160.0	3.25	−1.5
	220	2000	0.9937	0.3906	−255.1	109.1	2.54	−4.3
							Alg. Avg.	−2.1
							Abs. Avg.	2.6

tions for the 15 additional systems of Part 2 are somewhat greater than for Part 1, but the average for all systems is still less than 10% for all components except isopentane, and the over-all average deviation is only 7.1%. This confirms the utility of the charts for most engineering purposes.

Some of the larger deviations of Part 2 of this table must be attributed to failure of the charts to represent K-values accurately in mixtures containing high concentrations of cyclic hydrocarbons, as in the system methane-benzene. Others of the larger deviations are attributed to experimental error, as in mixtures of methane and ethylene and/or ethane, in which some of the reported equilibria are mutually inconsistent.

In the remainder of this section a more detailed comparison is made between the charts and observed K's for the first seven systems listed in Part 2 of Table 14. The purpose of this comparison is to show how far the charts may be extended to mixtures containing hydrocarbons differing in type or boiling point from those used in preparing the charts.

4.5 Five-Component Mixtures of Normal Paraffins. Hanson and Brown (*13*) have determined liquid-vapor equilibria in mixtures of methane, ethane, propane, *n*-butane and *n*-pentane, and a similar system with *n*-butane replaced by *n*-hexane. Table 15 shows that the individual K-values observed in these mixtures agree with those read from the charts within deviations that are no greater than would be expected in view of the analytical difficulties in such mixtures. This comparison shows that the charts, which were calculated for binary mixtures of paraffins, are reliable when applied to multicomponent mixtures of paraffins.

4.6 Solubility of Methane in Various Hydrocarbons. Table 16 compares K's for methane in *n*-hexane, cyclohexane, benzene and *n*-decane obtained from solubility measurements of Sage, Lacey and their co-workers with K's read from the charts. The mole fraction of methane in the vapor, which is nearly pure methane, was obtained with sufficient accuracy from an estimate of the K-value of the solvent. K-values observed for methane in the paraffins *n*-hexane and *n*-decane are in good agreement with those read from the charts. The agreement for *n*-decane, which is heavier than any of the hydrocarbons used in preparing the charts, shows that the effect of heavy paraffins may be taken into account by using the molal average boiling point as a characterizing variable.

When methane is dissolved in cyclohexane, the observed K's are systematically higher than the charts by 13% on the average. When cyclohexane is replaced by benzene, the deviations increase to an average of 39%. This shows that a correction for hydrocarbon type not accounted for by the use of molal average boiling point is needed for mixtures rich in naphthenic or aromatic hydrocarbons.

4.7 Natural Gas-Distillate System. Despite the significant error of the charts when the solvent is completely nonparaffinic, the charts are satisfactory for most of the light hydrocarbon mixtures of practical interest. For example, one of the most valuable applications of the charts described in this paper is to natural gas-distillate mixtures. Liquid-vapor equilibria in such a mixture have been observed experimentally by Roland, Smith and Kaveler (*24*) at 40°, 100° and 200° F. Table 17 lists all states observed experimentally by these investigators at 40° and 200° F., and compares K's for methane, ethane and propane with those read from the charts. A quantitative comparison could not be made for heavier hydrocarbons because these investigators did not analyze for the individual isomers, and the reported K's refer to a mixture of isomers in unknown proportions. It was noted, however, that K's reported for butane and pentane in most cases fell between those for the iso- and normal hydrocarbons as read from the charts.

The agreement between the observed K's for methane, ethane and propane is satisfactory, particularly when it is remembered that the liquid phase contains small proportions of hydrocarbons much

TABLE 17.—LIQUID-VAPOR EQUILIBRIA IN GAS-DISTILLATE SYSTEM (*22*)

COMPARISON OF OBSERVED *K*'s WITH CHARTS

Temp., °F.	Press., lb./sq.in.abs.	Mole Avg. B.P. Vapor	Mole Avg. B.P. Liquid	Observed *K* Methane	Observed *K* Ethane	Observed *K* Propane	Per Cent Deviation in *K*, 100 (Obs.-Chart)/Obs. Methane	Ethane	Propane
40	291	−245.8	+170.8	10.20	1.40	0.35	+19	0	−7.4
40	293	−248.9	+155.9	9.938	1.142	0.295	+18	−21	−26
40	395	−247.0	+137.3	7.207	1.103	0.319	+12	+2.6	+3.4
40	499	−252.3	+120.4	6.290	0.601	.....	+19	−58	.....
40	583	−244.1	+87.1	5.090	0.820	0.250	+13	−3.2	−6
40	765	−248.5	+68.1	3.929	0.701	0.226	+11	−1.0	+0.9
40	901	−249.4	+54.5	3.553	0.663	0.210	+11	−3.2	−3.7
40	1061	−248.2	+19.7	2.950	0.623	0.220	+7.5	−3.4	−3.6
40	1123	−245.6	+33.0	2.977	0.626	0.205	+11	−6.4	−20
40	1301	−246.1	+6.5	2.547	0.603	0.233	+7.1	−6.1	−6.4
40	1553	−248.9	−5.8	2.289	0.618	0.270	+9.3	−2.9	+5.2
40	1760	−244.8	−43.0	1.990	0.629	0.305	+5.9	−8.0	−1.3
40	1820	−247.4	−30.4	2.020	0.628	0.302	+6.7	−7.3	−1.7
40	2055	−246.0	−48.9	1.847	0.654	0.348	+4.7	−9.0	+0.9
40	2320	−242.8	−61.1	1.736	0.682	0.381	+4.0	−1.3	−8.7
40	2320	−243.7	−67.0	1.701	0.665	0.368	+2.6	−16	−12
40	2560	−241.6	−79.0	1.599	0.739	0.467	+1.5	−7.0	−2.4
40	2825	−237.8	−99.2	1.479	0.772	0.510	+0.4	−6.5	−12
40	2960	−232.6	−102.6	1.440	0.830	0.600	+0.5	−4.9	+0.3
40	3049	−234.4	−114.6	1.382	0.835	0.634	−1.4	−2.8	+5.2
200	521	−229.8	+171.0	6.193	2.411	1.087	+5.9	+2.1	+2.4
200	535	−236.0	+171.4	7.66	2.50	1.10	−7.1	+7.2	+5.0
200	587	−230.6	+161.6	7.316	2.170	0.957	+5.6	+1.4	−1.1
200	1040	−236.4	+34.1	3.567	1.355	0.663	−6.0	+9.6	+1.7
200	1373	−238.6	+61.2	2.85	1.24	0.66	−13	−3.9	+6.1
200	1820	−236.8	+34.6	2.574	1.028	0.590	+0.5	−4.3	−2.5
200	2248	−245.7	+12.1	2.23	0.99	0.61	+0.9	+5.1	+8.2
200	2322	−235.1	−5.6	1.880	0.964	0.580	−11	−2.4	−3.8
200	2764	−233.1	−18.1	1.92	0.99	0.615	+1.6	−5.6	+3.1
200	2825	−228.6	−45.0	1.735	0.931	0.642	−1.3	−1.3	+5.8
200	3485	−207.3	−98.3	1.341	1.037	0.824	−3.4	+6.1	+8.5
				Average Per Cent Deviations,		Alg.	+4.4	−4.9	−2.1
						Abs.	7.1	7.1	5.9

heavier than those for which the charts were computed. The absolute average deviations of 7.1% for methane and ethane and 5.9% for propane are of the same order of magnitude as for the 12 selected binary and ternary mixtures of light hydrocarbons discussed earlier. This excellent agreement of the charts with observed *K*'s confirms the reliability of the charts for calculating liquid-vapor equilibria in natural gas-distillate systems.

4.8 Absorption Oil. To extend the range of mixtures to which the charts might be applied still further, a comparison has been made between chart *K*'s and those observed by Webber (*34*) for synthetic mixtures of light hydrocarbons and an absorption oil with a molal average boiling point of 493° F. This oil contained 24.0% aromatics and 36.7% naphthenes, and had a value of 11.4 for Watson's characterization factor.

Table 18 lists a selection of the equilibrium states observed by Webber and compares the *K*'s observed with those read from the charts in all cases except those in which only traces of a component were present in one of the phases. To reduce analytical difficulties, Webber worked with individual isomers of butane and pentane, rather than with mixtures, so that reliable *K*'s were obtained for these hydrocarbons as well as for methane, ethane and propane. Although the average deviations of chart *K*'s from *K*'s observed for this system are greater than for the natural gas-distillate system, they are still small enough to permit use of the charts for engineering calculations in this type of system. It is concluded that the charts may be used for mixtures with hydrocarbon absorption oils whose characterization factors lie above 11.4. It is noted that the charts, at least for methane, are not reliable for benzene, with a characterization factor of 9.7.

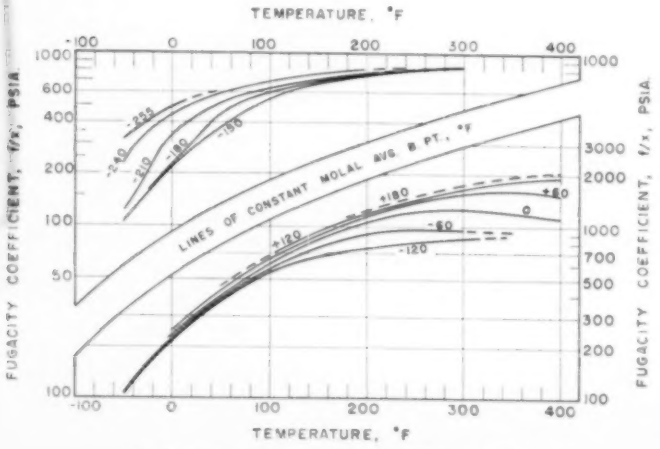


Fig. 10. Fugacity coefficient of ethane at 1000 lbs./sq.in. abs.

5. Evaluation of Charts

During the past ten years, these charts have been used for prediction of liquid-vapor equilibria in a large number of engineering problems, and their reliability and utility have been demonstrated. The reliability of the charts has been confirmed by their agreement with the new experimental data which have appeared since the charts were prepared, in 1941, and by the satisfactory performance of processes and equipment designed with their aid. The charts call for somewhat more effort than conventional *K*-charts, but their use has proved advantageous (1) whenever *K*-values more accurate than 20% are required, (2) for methane under all conditions, (3) for any of the other 11 hydrocarbons at pressures above 300 lb./sq.in.abs., and whenever their normal

boiling point differs from the molal average boiling point of either phase by more than 100° F.

The charts may be used for mixtures containing non-hydrocarbon gases such as hydrogen, nitrogen or carbon dioxide, or hydrocarbons heavier than heptane, provided the molal average boiling point of both phases falls within the range covered by the charts.

The charts are reliable except (1) when K-values more accurate than 5% are required, (2) when the pressure is within 50 lb./sq.in.abs. of the critical pressure of either phase, (3) when the characterization factor of either phase is less than 11.4, (4) when either phase contains more than 30% of a polar compound, or (5) when the pressure, temperature or molal average boiling point is so far outside the range of the charts as to preclude reliable extrapolation. In exceptions (1) and (2) reliable K-values may be secured by use of the fugacity coefficient equations given in the preceding paper of this series (*5*).

It is the authors' belief that the set of charts (*19*) described in this paper represents the most satisfactory compromise between simplicity and accuracy of any means now available for predicting liquid-vapor equilibria in mixtures of light hydrocarbons.

Acknowledgments

Grateful acknowledgment is made to Arthur Lionel, Bernard Piscopo, Martin Schlesinger, Richard Trainor, John Umber and William Volk for their assistance in constructing these charts and calculating fugacities, and to Marjorie A. Benedict for her help in preparing this paper.

The financial assistance of the Polymerization Process Corp. is acknowledged with thanks.

Literature Cited

1. Benedict, M., Solomon, E., and Rubin, L. C., *Ind. Eng. Chem.*, **37**, 55 (1945).
2. Benedict, M., Webb, G. B., and Rubin, L. C., *J. Chem. Phys.*, **8**, 334 (1940).
3. Benedict, M., Webb, G. B., and Rubin, L. C., *Ibid.*, **10**, 747 (1942).
4. Benedict, M., Webb, G. B., and Rubin, L. C., *Chem. Eng. Progress*, **47**, 419 (1951).
5. Benedict, M., Webb, G. B., and Rubin, L. C., *Ibid.*, **47**, 449 (1951).
6. Billman, G. W., Sage, B. H., and Lacey, W. N., *Am. Inst. Mining Met. Engrs., Tech. Pub.* No. 2232 (1947).
7. Carter, R. T., Sage, B. H., and Lacey, W. N., *Ibid.*, No. 1250 (1940).
8. Cummings, L. W. T., Thesis, Mass. Inst. Technol., Chem. Eng. Dept. (1933).
9. Cummings, L. W. T., Stone, F. W., and Volante, M. A., *Ind. Eng. Chem.*, **25**, 728 (1933).

TABLE 18.—LIQUID-VAPOR EQUILIBRIA OF HYDROCARBONS IN ABSORPTION OIL AT 100° F. (*21*)

COMPARISONS OF OBSERVED K's WITH CHARTS

Pressure, lb. sq.in.abs.	500	1000	1500	1800	1000	1600	1800	2000	2500	2600	2800	2000
Mole Fraction in Vapor												
Methane	0.8728	0.9550	0.9477	0.9545	0.9509	0.9575	0.9601	0.9613	0.9215	0.9382	0.9076	0.8490
Ethane	0.0114	0.0181	0.0222	0.0192	0.0225	0.0212	0.0203	0.0203	0.0322	0.0244	0.0294	0.0223
Propane	0.0525	0.0115	0.0018	0.0009	0.0024	0.0042	0.0006	0.0042	0.0020	0.0050	0.0041	0.0020
Isobutane	0.0185	0.0058	0.0014	0.0004	0.0012	0.0013	0.0004	0.0010	0.0010	0.0010	0.0010	0.0010
n-Butane	0.0385	0.0058	0.0014	0.0004	0.0012	0.0013	0.0004	0.0010	0.0010	0.0010	0.0010	0.0010
Isopentane	0.0082	0.0252	0.0014	0.0004	0.0012	0.0013	0.0004	0.0010	0.0010	0.0010	0.0010	0.0010
n-Pentane	0.0115	0.0252	0.0014	0.0004	0.0012	0.0013	0.0004	0.0010	0.0010	0.0010	0.0010	0.0010
n-Hexane	0.0115	0.0252	0.0014	0.0004	0.0012	0.0013	0.0004	0.0010	0.0010	0.0010	0.0010	0.0010
Mole Fraction in Liquid												
Methane	0.1282	0.2598	0.2208	0.2324	0.2186	0.2667	0.2227	0.4173	0.3752	0.3896	0.3682	0.4320
Ethane	0.0039	0.0210	0.0271	0.0267	0.0252	0.0231	0.0226	0.0275	0.0411	0.0360	0.0372	0.0305
Propane	0.1123	0.0073	0.0016	0.0023	0.0040	0.0029	0.0009	0.0086	0.0053	0.0116	0.0093	0.0046
Isobutane	0.0593	0.0016	0.0003	0.0001	0.0003	0.0003	0.0001	0.0020	0.0013	0.0026	0.0021	0.0010
n-Butane	0.1166	0.0042	0.0007	0.0002	0.0006	0.0006	0.0002	0.0039	0.0026	0.0050	0.0040	0.0019
Isopentane	0.0948	0.0155	0.0027	0.0007	0.0022	0.0022	0.0006	0.0066	0.0044	0.0084	0.0067	0.0031
n-Pentane	0.1169	0.0193	0.0033	0.0009	0.0027	0.0027	0.0008	0.0081	0.0054	0.0103	0.0082	0.0038
n-Hexane	0.4553	0.0267	0.0033	0.0009	0.0027	0.0027	0.0008	0.0081	0.0054	0.0103	0.0082	0.0038
Absorption Oil	0.2221	0.2672	0.3708	0.3652	0.4578	0.2815	0.2980	0.2817	0.3340	0.2830	0.3202	0.3202
Mole Avg. B.P., ° F.												
Vapor	228.6	−247.2	−228.2	−247.5	−240.8	−248.7	−244.0	−241.6	−233.2	−238.3	−233.0	
Liquid	109.3	104.8	114.3	122.7	116.8	104.2	115.8	92.8	114.1	91.1	107.4	
Observed K												
Methane	6.85	3.67	4.16	4.11	4.21	3.59	4.04	2.46	2.40	2.46	2.48	
Ethane	2.87	0.83	0.87	0.72	.....	0.91	0.795	0.80	.....	.....	.....	
Propane	0.467	.....	.....	.....	.....	.....	0.467	.....	.....	0.45	.....	
Isobutane	0.165	.....	.....	.....	.....	.....	.....	.....	.....	0.29	.....	
n-Butane	0.107	.....	0.115	.....	.....	.....	.....	0.22	.....	.....	.....	
Isopentane	0.07	.....	.....	0.068	.....	0.064	.....	.....	0.135	.....	0.112	
n-Pentane	.....	0.052	.....	.....	.....	0.052	.....	0.177	.....	.....	.....	
n-Hexane	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.064	
Per Cent Deviation in K from Oil-Chart Obs.												
Methane	19.0	+11	+10	+13	+10	+12	+10	+10	+7.7	−2.4	+7.3	−2.7
Ethane	.....	+9.4	−14	.....	−14	−15	−13	.....	.....	.....	−16	−16
Propane	±6.	.....	.....	.....	.....	−20	.....	.....	.....	.....	−12	−7.5
Isobutane	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	−0.7	13.1
n-Butane	19.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.1
Isopentane	24.3	.....	−18	.....	.....	.....	.....	.....	.....	.....	.....	17.9
n-Pentane	.....	+7.0	.....	−13	.....	.....	.....	.....	.....	.....	.....	15
n-Hexane	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.9
						−14						
						.....						
						−2.1						
						.....						
						.....						
						−16						
						.....						
						.....						
						.....

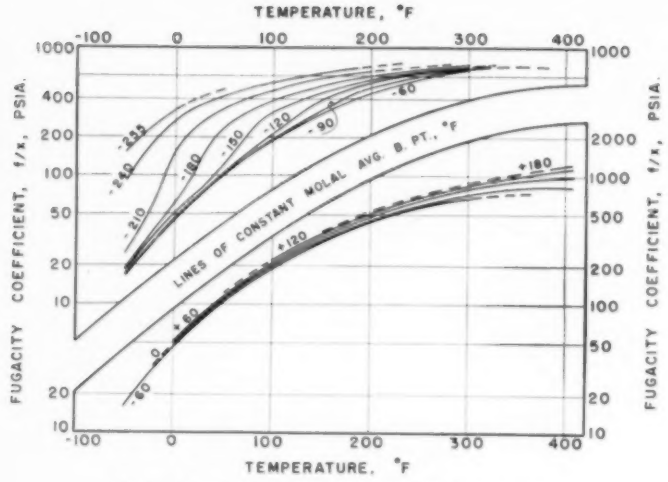


Fig. 11. Fugacity coefficient of propane at 1000 lbs./sq.in. abs.

10. Dourson, R. H., Sage, B. H., and Lacey, W. N., *Am. Inst. Mining Met. Engrs., Tech. Pub.* No. 1490 (1942).
11. Gilliland, E. R., and Scheeline, H. W., *Ind. Eng. Chem.*, **32**, 48 (1940).
12. Guter, M., Newitt, D. M., and Ruhemann, M., *Proc. Roy. Soc.* (*London*), **176A**, 140 (1940).
13. Hanson, G. H., and Brown, G. G., *Ind Eng. Chem.*, **37**, 821 (1945).
14. Hough, E. W., and Sage, B. H., *Chem. Rev.*, **44**, 193 (1949).
15. Kay, W. B., *Ind. Eng. Chem.*, **30**, 459 (1938).
16. Kay, W. B., *Ibid.*, **32**, 353 (1940).
17. Kay, W. B., *Ibid.*, **33**, 590 (1941).
18. Kay, W. B., *Ibid.*, **40**, 1459 (1948).
19. Kellogg Equilibrium Charts, *Chem. Eng. Progress*, **46**, No. 3, 20 (1950).
20. Lavender, H. M., Sage, B. H., and Lacey, W. N., *Oil Gas J.*, **39** (9), 48 (1940).
21. Nysewander, C. N., Sage, B. H., and Lacey, W. N., *Ind. Eng. Chem.*, **32**, 118 (1940).
22. Olds, R. H., Sage, B. H., and Lacey, W. N., *Ibid.*, **34**, 1008 (1942).
23. Quinn, J. C., Thesis, Mass. Inst. Technol., Chem. Eng. Dept. (1940).
24. Roland, C. H., Smith, D. E., and Kaveler, H. H., *Oil Gas J.*, **39** (46), 128 (1941).
25. Ruhemann, M., *Proc. Roy. Soc.* (*London*), **171A**, 121 (1939).
26. Sage, B. H., Hicks, B. L., and Lacey, W. N., *Ind. Eng. Chem.*, **32**, 1085 (1940).
27. Sage, B. H., and Lacey, W. N., *Ibid.*, **32**, 992 (1940).

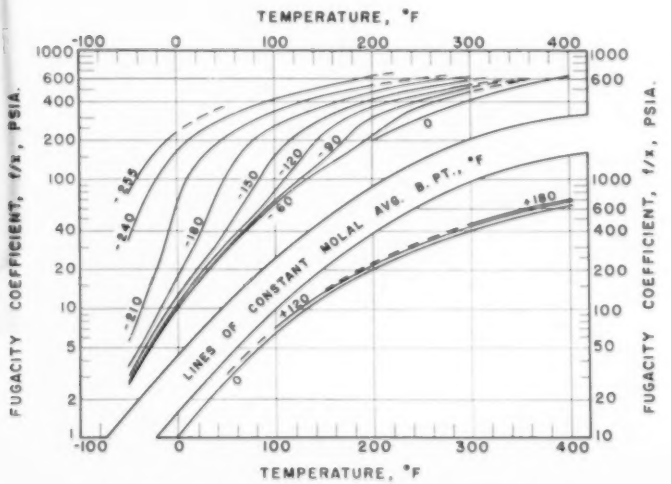


Fig. 12. Fugacity coefficient of n-Butane at 1000 lbs./sq.in. abs.

28. Sage, B. H., Lacey, W. N., and Schaafsma, J. G., *Ibid.*, **26**, 214 (1934).
29. Sage, B. H., Webster, D. C., and Lacey, W. N., *Ibid.*, **28**, 1045 (1936).
30. Scheeline, H. W., and Gilliland, E. R., *Ibid.*, **31**, 1050 (1939).
31. Sherwood, T. K., "Absorption and Extraction," McGraw-Hill, New York (1937).
32. Taylor, H. S., Wald, G. W., Sage, B. H., and Lacey, W. N., *Oil Gas J.*, **38** (10), 46 (1939).
33. Volova, L. M., *J. Phys. Chem.* (U.S.S.R.), **14**, 268 (1940).
34. Webber, C., *Am. Inst. Mining Met. Engrs., Tech. Pub.* No. 1252 (1940).

Discussion

John Happel (New York University, New York 53, N. Y.): Dr. Benedict, would you care to comment on the reliability of the predictions in the region of the critical. In other words, what is the accuracy of the data in comparison with the reported five per cent or so over the entire range of variables? And can this type of chart be employed in calculations involving fixed gases, particularly mixtures that might contain hydrogen?

Manson Benedict: In answer to Professor Happel's first question—the reliability of the charts falls off, within around 50 lb./sq.in. of the critical pressure. If one has to make calculations within 50 lb./sq.in. of the critical pressure, we recommend use of the equation of state rather than these charts.

In mixtures containing fixed gases, so long as the molal average boiling point is within the range covered by the charts, and these go down to −255° F., fugacities of hydrocarbons are adequately represented. If the hydrogen content of mixture is too high, its molal average boiling point is below −255° F., and an extrapolation of the charts is required. We are extending the charts to lower molal average boiling point, but this information is not yet generally available.

Anonymous: What is the average molal boiling point, and how do you determine it?

Manson Benedict: The molal average boiling point is a calculated index of the volatility of the mixture. It is evaluated by taking the sum of the product of the mole fraction and boiling point for every component of the entire mixture. To give a simple example, the molal average boiling point of a mixture of 50 mole % propane (b.p. −44° F.) and 50 mole % isobutane (b.p. +11° F.) is −16.5° F.

(The End)

(Presented at Forty-second Annual Meeting, Pittsburgh, Pa.)

MASS-TRANSFER RATES ON BUBBLE PLATES

PART II

RESULTS FOR LARGE TRAYS

J. A. GERSTER, W. E. BONNET†, and IRWIN HESS‡

University of Delaware, Newark, Delaware

ALL results and conclusions presented thus far have been based upon data obtained in a 13-in. diam. column, and applicability of these results to larger columns must be evaluated.

It is not expected that gas film efficiency would be greatly affected by plate width provided the foam height and gas distribution across the tray is fairly uniform. Under these conditions the gas film efficiency for a large tray could be obtained from experimental data obtained in a smaller column, provided proper allowance for changes in foam height and foam density were made according to methods outlined in Part I. If the large tray were operated with an appreciable hydraulic gradient, most of the gas would pass through caps nearest the outlet weir. Under these conditions a local gas efficiency for each row of caps could be predicted from estimated gas and liquid properties at each cap row, arrived at by means of hydraulic gradient correlations (*3, 6*). Averaging the local efficiencies to obtain an over-all gas efficiency for the plate could then be carried out by totaling the amount of mass transferred in each row. This suggested procedure is cumbersome, however, and should be verified experimentally.

Plate width is an important factor affecting liquid film efficiency because, as mentioned earlier, the longer the path over which the liquid is contacted by gas bubbles the greater should be the liquid efficiency. In view of the large expected change in liquid efficiency with plate width, an experimental program was undertaken with a large tray section.

Experimental Test Unit. Tests were carried out with a center section of a 13-ft. diam. split-flow tray, the section being full size in the direction of liquid flow. As shown in Figure 9, liquid entered the tray at the center, was evenly split over two entrance weirs, and proceeded for a distance of 45 in. to the outlet weirs located at the outer ends of the unit. The tray section was 9½ in. wide, and since cap spacing was 9½ in. on equilateral triangular centers, the section was also one cap wide. Each half of the tray contained five rows of caps, corresponding to a total of five whole caps per side. Caps were 6¾ in. in diam. above the slots while the bottom 1½ in. of the cap, where the slots were located, was flared outward to a maximum diam. of 8 in. Each cap had 24 slots, each 1 5/16 in. high, open at the bottom, with 11/16-in. width at the bottom and 3/8-in. width at the top. The over-all cap height was 4.75 in. Cap risers were 4-in. standard pipe, cut to give a skirt clearance of ¾ in. The outlet weir height of these studies was 2½ in. The 13-ft. tower after which the experimental tray section was patterned, is an extractive distillation tower used for the separation of C_4 hydrocarbons with furfural as the solvent and has been described by Happel (*9*) as the "isobutane column." The liquid rate for the trays of this column in service varies from about 55 to 105 gal./(min.)(ft. of weir length), and the gas rate varies from 8.5 to 15.3 cu.ft./min. (at about 90 lb./sq.in. gauge pressure).

Foam Height and Foam Density Measurements. Since foam height and foam density are factors of prime importance for correlating tray performance, these properties were determined for the large tray section with air and water at 1 atm. Foam densities for the large tray section are plotted in Figure 3, where it may be seen that at any given gas rate the water on the large tray was not as highly aerated as that on the small 13-in. tray. This is mainly due to the nonuniformity of slot location on the tray, caused by the excessively large diameter and close spacing of the caps.

Actual foam heights of the large tray when operating with a 2½-in. outlet weir were measured over a wide range of gas and liquid rates. Results are included in Figure 4 and show that the same correlation obtained for the small 13-in. tray is valid for the larger tray.

Liquid Film Efficiencies. Oxygen desorption tests were carried out with the large tray section, using the same procedures followed for the smaller tray. Liquid film efficiencies were measured at liquid rates up to 125 gal./min. and at vapor rates up to 6 ft./sec. based on the total bubbling area. Runs with zero gas flow showed that sufficient oxygen was lost from the water flowing across the plate to give liquid plate efficiencies increasing uniformly from 1.7% at 25 gal./min. to 7.0% at 100 gal./min. In this case, although the liquid turbulence is rather high, the extremely low interfacial area per unit volume of liquid limits the amount of mass transfer.

The lowest gas rate studied was 0.8 ft./sec. based on the bubbling area, which corresponds to the same slot velocity employed in the lowest gas rate

Part I of this article covering Fundamental Factors was run in October, 1951, "C.E.P." The article concludes with this issue.

† Present address: Sun Oil Co., Marcus Hook, Pa.

‡ Present address: The Du Pont Co., Martinsville, Va.

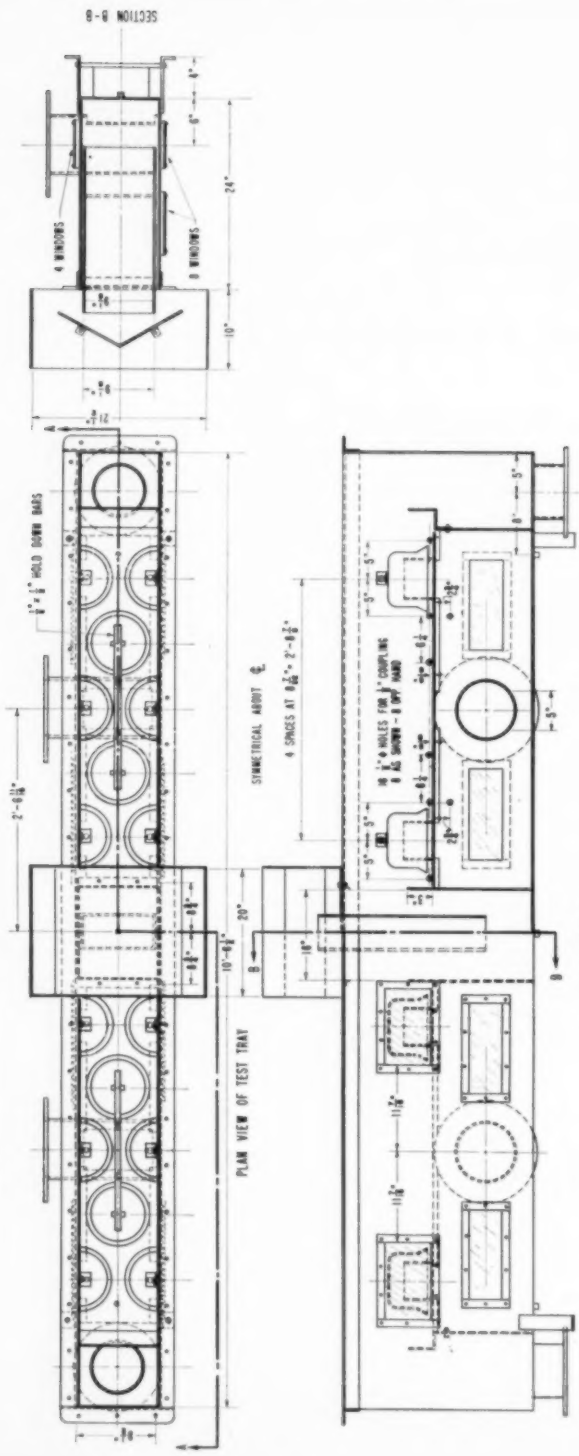


Fig. 9. Section of 13-ft. diam. split flow tray used in plate efficiency determinations.

runs for the 13-in. diam. column. Liquid film efficiencies for the large tray at this gas rate varied from 50% at a total liquid flow rate of 25 gal./min. down to 13% at 100 gal./min.; at this low gas rate, however, the plate was unstable due to hydraulic gradient and all the caps did not bubble above a liquid rate of 40 gal./min. At a moderately high gas rate of 2.5 ft./sec., based on the bubbling area, which corresponds to the same slot velocity as that for the highest gas rate runs for the 13-in. diam. column, liquid efficiencies varied from 88% at a total liquid flow rate of 25 gal./min. down to 50% at 100 gal./min. At this gas rate all caps did not bubble above a liquid rate of 60 gal./min. These liquid efficiency results are surprising when a comparison is made between liquid efficiency results of the large tray and those for the 13-in. diam. tray; at the same latter gas rate and a liquid flow of 50 gal./min. efficiencies were 52% for the large tray and 80% for the small tray. These differences are explained later.

A quantitative presentation of results is given in Figure 10, with performance of the large tray plotted in terms of H_L, the length of liquid travel required to give a performance equivalent to one transfer unit. Values of H_L were computed as before, with the length of liquid travel taken as 45 in. or 3.75 ft. Performance results are plotted as a function of maximum linear liquid velocity based upon the minimum area available for liquid flow. This minimum area was taken as the total distance between adjacent caps ($2\frac{3}{4}$ in.) multiplied by the height of equivalent clear liquid; this height was computed as the outlet weir height plus the liquid height over the weir computed by the Francis formula (*14*). Results in Figure 10 are also given as a function of gas rate expressed as ft./sec. based on the bubbling area of 2.97 sq.ft. Plotted beside each point of Figure 10 is the number of caps actively bubbling on each side of the split-flow tray. Reference to this plot shows that for cases of high liquid flow and low gas flow as few as one of the five whole caps per side actively bubbles.

Values of H_L for any gas rate increase quite rapidly and uniformly up to a liquid rate of around 75 gal./min. Up to this value of liquid rate, H_L is seen to increase as the 1.5 power of the liquid rate, representing a faster decrease in plate performance than was found for the small diameter plate. The additional factor of decreasing plate stability with increasing liquid rate is evidently responsible for this.

Above 75 gal./min., a dip in the results occurs until a new line sloping upwards to the right is formed. This

new line corresponds to a new vapor velocity, since the number of active caps has changed in the "dip" region. For example, the line for a gas rate of 2.8 ft./sec. in the region of highest liquid rate appears to be an extension of the line for a gas rate of 5.0 ft./sec. in the region of lowest liquid rate; since in the first case only 3 caps actively bubble while in the second case all 5 caps bubble; the "effective" gas velocity in the first case is $\frac{3}{5}$ of 2.8 ft./sec. or nearly 5 ft./sec., which is comparable to the gas velocity and therefore to the results of the second case.

Quantitative treatment of all the results in this manner is not feasible in view of the complicated way in which the gas rate through each cap changes with liquid rate; the effect of gas rate alone on N_L was shown in an earlier section to be quite complicated. As a means of eliminating the effect of nonuniformity in gas rate, a series of liquid efficiency tests was made for the same tray section with a nearly uniform gas distribution to each cap. Such tests provided information wherein the effect of fundamental factors, such as gas and liquid rates, foam density, and length of liquid travel could be studied; they also permitted comparison of the performance of a "stable" tray with that of an "unstable" tray.

Liquid Film Efficiencies for the Large Tray Modified to Give Uniform Bubbling. The instability of the large split-flow tray section, when operating at extractive distillation flow rates, prompted a comprehensive study of methods whereby such instability could be corrected. The results of this study have been reported elsewhere (*2*); the quantitative effects of blocking off caps and/or slots, of raising the outlet weir height, of raising cap slots nearest the inlet weir, and of inserting restrictions in the cap risers are presented in detail. Of all these methods, the latter proved one of the most effective for giving uniform bubbling over a wide range of operating conditions, but at the expense of additional gas pressure drop. The scheme, used for the series of runs presented below, involved insertion of orifices of varying size into the cap risers, the smallest orifice being installed nearest the outlet weir and the largest nearest the inlet weir. Exact sizes of these restrictions were 1.58, 1.47, 1.40, 1.35, and 1.30 in., one for each of the five caps on each tray side.

Liquid film efficiency results obtained by oxygen desorption methods for the large tray section as modified above are given in Table 1 and plotted in Figure 11. Gas and liquid rates are given in the same units as for Figure 10. Results are seen to be quite uniform, and are qualitatively similar to those obtained with the small diameter tray in that H_L increases with increasing liquid rate and decreases with increasing gas rate.

The effect of liquid rate on H_L may again be broken down into its effect upon interfacial area and liquid contact time. Consider, for example, the effect of a change in liquid rate at a constant gas rate of 1.6 ft./sec. At a liquid rate of 20 gal./min. the foam height is 6.3 in., while at a liquid rate of 80 gal./min. the foam height is 11.2 in. These values are taken from Table 1. The interfacial area is proportional to the function $(1-\phi)/Z_f$ and, at constant gas rate, where ϕ is a constant, is proportional only to Z_f, the foam height. At 80 gal./min., the interfacial area should be $11.2/6.3 = 1.78$ times greater than at 20 gal./min. Since the actual value of H_L at 80 gal./min. is 5.1 ft., the corresponding value of H_L, corrected to the same interfacial area as at 20 gal./min., is $(5.1)(1.78) = 9.1$ ft. Noting that the actual value of H_L at 20 gal./min. is 3.05 ft., the effective time of contact at the lower liquid rate is $9.1/3.05 = 3.0$ times greater than at the higher rate.

In an earlier section liquid contact time for the small diameter plate was shown to be proportional to $Z_f\phi/q$ which for constant gas rate reduces to Z_f/q. The ratio of contact times for liquid rates of 20 and 80 gal./min. at the gas rate of 1.6 ft./sec. is 2.2 when predicted as Z_f/q for 20 gal./min. divided by Z_f/q for 80 gal./min. The experimental value of 3.0 is much higher, indicating that the liquid does not remain on the

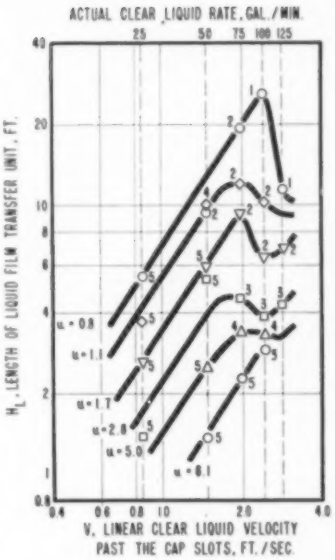


Fig. 10. Liquid film performance of large tray section as a function of liquid rate. Parameter is *u*, superficial vapor velocity based on bubbling area, ft./sec. Numbers beside points refer to number of cap rows actively bubbling.

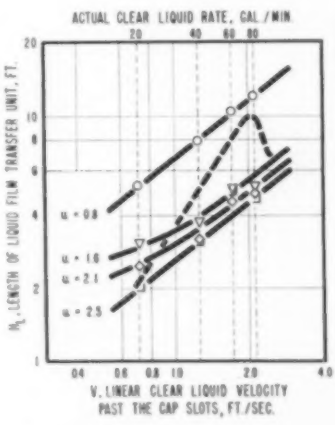


Fig. 11. Liquid film performance of large tray section modified to give uniform gas bubbling as a function of liquid rate. Parameter is *u*, superficial vapor velocity based on bubbling area, ft./sec. Dashed line shows comparable performance of unmodified tray at value of $u = 1.6$ ft./sec.

TABLE 1.—DATA AND RESULTS OF OXYGEN DESORPTION TESTS FOR LARGE TRAY SECTION MODIFIED TO GIVE UNIFORM BUBBLING

Run No.	Superficial Gas Rate, *u* ft./sec.	Clear Liquid Rate, *q* gal./min.	Clear Liquid Linear Velocity Past Cap Slots, *V*, ft./sec.	Foam Height, Z_f, in.	Liquid Plate Efficiency, E_L, %	Length of a Liquid Film Transfer Unit, H_L, ft.
47	0.8	20	0.71	4.5	50.9	5.25
48	1.6	20	0.71	6.3	71.0	3.05
49	2.1	20	0.71	6.3	77.8	2.45
50	2.5	20	0.71	6.2	85.2	1.98
51	0.8	40	1.23	6.5	37.9	7.90
52	1.6	40	1.23	7.7	63.9	3.69
53	2.1	40	1.23	9.2	70.0	3.15
54	2.5	40	1.23	8.2	70.7	3.05
55	0.8	60	1.70	6.5	30.1	10.50
56	1.6	60	1.70	8.2	53.2	4.95
57	2.1	60	1.70	9.4	55.9	4.55
58	2.5	60	1.70	10.4	53.0	4.95
59	0.8	80	2.08	7.6	27.2	11.80
60	1.6	80	2.08	11.2	51.7	5.15
61	2.1	80	2.08	11.2	53.0	4.95
62	2.5	80	2.08	12.2	55.8	4.60

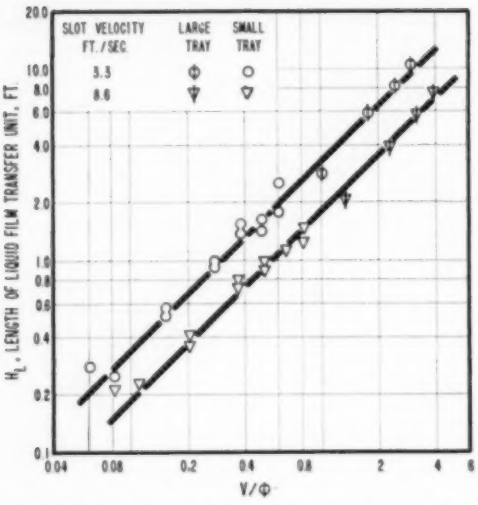


Fig. 12. Effect of froth velocity upon liquid film performance of large and small trays. Liquid performance is plotted in terms of H_L corrected to a foam height of 6 in.; H_L values for the large tray were further corrected to the same degree of liquid aeration obtained with the small tray. Liquid rate is expressed in terms of V/ϕ, where V is the linear clear liquid velocity based on minimum clear liquid cross section of ϕ is the froth density, g./cc.

plate at the higher liquid rate as long as would be expected from theory. This may be explained by noting that at the lower liquid rate, where $Z_f = 6.3$ in., most of the liquid flows between the caps since the top of the cap is 5.5 in. above the tray floor, while at the higher liquid rate, where $Z_f = 11.2$ in., much of the liquid flows above the caps. With the large diameter, closely spaced caps used on this tray, the resistance to flow for the liquid above the caps is much lower, permitting a higher local linear velocity in this region. Exact mathematical treatment of this case appears too complicated to be practical, and as a simplifying approximation, the use of ϕ/V as a measure of the time of contact is suggested, where V is the linear clear liquid velocity based on the minimum clear liquid cross section. This liquid velocity has been used previously as a correlating variable in Figures 6, 8, 10, and 11. For the case above where the experimental ratio of contact times was 3.0, the linear clear liquid velocities corresponding to 80 and 20 gal./min. are 2.1 and 0.72 ft./sec. Since the gas rate and ϕ are constant in this example, the predicted ratio of contact times would be 2.1/0.72 or 2.9. More conclusive evidence that ϕ/V may be used to represent liquid time of contact is shown in Figure 12, which is discussed later.

The effect of a change in gas rate is predicted to be fairly small, according to the theoretical methods developed above for the small plate. This condition is apparently realized in Figure 11 at the higher gas rates.

An interesting comparison between the modified and unmodified large tray is also shown in Figure 11. The dashed line on this figure represents the performance characteristic of the unmodified tray at a gas rate of 1.6 ft./sec. as interpolated from Figure 10. Comparison of this dashed line with that for the tray modified to give uniform gas bubbling at the same gas rate, shows the erratic nature of the efficiency for the unmodified tray as fewer and fewer caps bubble when the liquid rate is increased. Although the values of H_L for the two tray designs are not widely different at low and high liquid rates, the uncertainty of performance in the intermediate liquid range would lead to the recommendation that all future trays be designed to insure uniform gas bubbling.

Comparison of Results for Large and Small Trays. In comparing results for the large and small trays, it should be remembered that the wide difference in cap size and spacing produced different aeration factors on the two trays at comparable slot velocities. Also, the difference in tray layout caused different linear clear liquid velocities on the two trays at comparable values of liquid rate expressed as gal. of clear liquid/(min.) (ft. of tray width). In order to make a comparison of the results of the two trays, H_L values were assembled at constant slot velocities of 3.3 and 8.6 ft./sec., the first of which corresponded to superficial vapor velocities of 0.58 and 0.80 ft./sec. for the small and large trays respectively; and the second of which corresponded to 1.51 and 2.10 ft./sec. for the small and large trays. Results from the present study do not clearly indicate that equivalent slot velocity should be chosen as the basis of comparison for two trays of different slot size and spacing. The problem requires further study based on many trays of varied design. A second step was to correct these values of H_L to a constant foam height of 6 in. so that all values for any one tray could be compared at constant interfacial area. This correction was made by multiplying H_L values by the ratio $Z_f/6$ where Z_f is the experimental foam height in inches. Since interfacial area is also proportional to $(1-\phi)^{2/3}$, and since ϕ varied at constant gas rate with the tray design, the H_L values for the large tray were multiplied by $[(1-\phi)_{\text{large tray}}/(1-\phi)_{\text{small tray}}]^{2/3}$ so they could be compared with the H_L values for the small tray. The values of H_L corrected in this manner to a common condition of interfacial area were plotted as a function of l'/ϕ to test the validity of this relationship to express time of contact of the liquid with the gas, and to bring together liquid film results obtained on two trays of widely different length of liquid travel, cap size, and cap spacing. Figure 12 is such a plot, with two lines shown for the two different slot velocities of 3.3 and 8.6 ft./sec. H_L values for this figure were taken from Figure 11 for the large plate, and those for the small plate were taken both from Figure 6, which was the case of zero skirt clearance and 4-in. outlet weir, and also from results for the case of ¾-in. skirt clearance and 4-in. outlet weir, since these latter two cases were shown to be comparable in Figure 8.

The results of Figure 12 show quite clearly that at any given slot velocity the corrected H_L values for both plates are correlated by a single straight line on the log-log plot of slope equal to unity. This plot to a great extent, not only validates many of the procedures and concepts suggested in this paper, but points the way for application of these results to predict efficiencies for plates of any design for which foam density or aeration factor data are known.

To summarize the steps necessary to correlate liquid film efficiency results for the large and small trays:

It was first necessary to express the liquid performance in terms of the length of a transfer unit since performance was shown to increase directly as the length of liquid travel. It was next required to plot the results at constant slot velocity and at

constant interfacial area as a function of the time of contact expressed as L'/ϕ.

Probably the most important conclusion to be reached from Figure 12 is that the high linear liquid rate on the large tray section is most responsible for its poor liquid film performance. The large caps of this tray were spaced so closely that the resulting linear liquid velocity past the slots was quite high. Smaller, wider-spaced caps would be much better, provided such a change would not greatly raise the aeration factor. Apparently a sieve tray would be most effective in reducing the linear liquid velocity. Further studies of aeration factor and liquid efficiency for many different tray designs are currently in progress in our laboratories, and should be of further help to attain the optimum design of bubble trays for any particular application.

Application of Single Film Efficiencies for Prediction of Over-all Efficiencies

The preceding section has shown how the single film efficiency data presented in this and in an earlier paper (*4*) may be extended to give single film results for plates of other designs and operating conditions. Methods for combining these gas film and liquid film efficiencies into an over-all efficiency for any system employed were suggested in the earlier paper, but further confirmation of these methods over a wider range of composition and at higher column pressures seemed desirable. New plate efficiency data are presented below for the methanol-water system at atmospheric pressure and at 50 lb./sq.in. gage pressure. These data were obtained at total reflux in a 13-in. diam. column, the plates of which were identical in design with the 13-in. tray having ¾-in. skirt clearance and 4-in. outlet weir, as used in the single film studies above. The column contained 10 stainless steel plates spaced 24 in. apart, and has been completely described previously (*8*).

Experimental. A series of six atmospheric pressure runs and four elevated pressure runs were made with the methanol-water system, all at the same superficial vapor velocity of 2.35 ft./sec. Upon attainment of steady state conditions, vapor samples were withdrawn from a small diameter tube extending to the center of the column a few inches below each plate. The removed vapors were totally condensed, and the rate of withdrawal of sample was kept to only a few tenths of a per cent of the total vapor flow rate. Vapor samples were felt to be more completely mixed and thus more representative than liquid samples. The samples were analyzed by determination of specific gravity with calibrated hydrometers. Reliability and consistency of the data were checked by plotting concentration profiles through the column and by calculation of overall heat balances.

Only five trays were considered in each run, as the remainder were in "pinch" regions where vapor concentrations did not change much. Over-all Murphree plate efficiencies for each tray considered were calculated as the actual change in methanol concentration in the vapor phase divided by the maximum change which would occur if the vapor left the tray in equilibrium with the liquid leaving the tray. Since operation was always at total reflux, the concentration of the vapor leaving any tray was, of course, equal to the concentration of the liquid leaving the tray above. Equilibrium data employed were those of Perry (*14*) at atmospheric pressure and those of Griswold (*7*) at higher pressures.

Plate efficiency results are shown plotted in Figure 13 as a function of the liquid concentration on the plate. For each pressure studied, the efficiency increases from around 65% at low methanol concentrations to around 90% at high methanol concentrations, although results were slightly higher for the higher pressure at low methanol concentrations.

Predicted Efficiencies for Methanol-Water System. As a first step in the prediction of plate efficiencies, vapor boil-up and overhead liquid condensate rates were calculated from the reboiler and condenser heat loads, from which the liquid and vapor rates at each plate were calculated by heat balances. The vapor rate was essentially constant from plate to plate for all runs, but the volumetric liquid rate decreased down the column as a result of the lower molecular weight and higher density of water. Values of N_G and N_L were obtained for each plate from the single film data of this paper at corresponding volumetric gas and liquid rates, and these values required no correction for plate design, which was the same for both the methanol-water tests and the single film tests. Volumetric gas and liquid rates were used as a basis for comparison for both the low and high pressure methanol-water runs.

The resulting single film values of N_G were then multiplied by the ratio $(N_{Sc}/N_{Sc}')^{\frac{2}{3}}$ to correct for the difference in physical properties between the methanol-water gas phase and the air-water gas phase of the single film studies. N_{Sc} is the Schmidt number for the methanol-water gas phase and consists of a dimensionless grouping of μ, gas viscosity, ρ, gas density, and D, gas diffusivity as follows: $N_{Sc} = \mu/\rho D$. N_{Sc}' is the corresponding group for the air-water gas phase. Mass-transfer theory has shown that most of the gas film resistance lies in the stagnant gas film next to the gas-liquid interface where laws of molecular diffusion govern the transfer rate, and values of N_G vary from one system to another at comparable flow rates as the ratio of the Schmidt numbers raised to a fractional power, probably ⅔. To evaluate the Schmidt groups, viscosities of the gases as a function of temperature and pressure were taken from Perry (*14*), gas densities were calculated from the ideal gas laws, and gas diffusivities calculated from the equation of Gilliland (*5*). For the air-water vapor system at temperatures and pressures employed in the single film studies, the value of the Schmidt number is 0.60. For methanol-water vapor at 100° C., the value of the Schmidt group at low methanol concentrations is 0.77, while at high methanol concentrations, the value is 0.43. Variation of these values with temperature did not exceed 10%, and values at intermediate concentrations were linearly interpolated from the two values at infinite

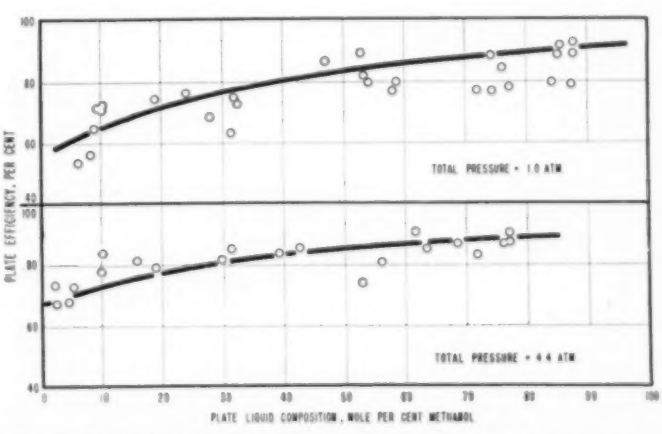


Fig. 13. Plate efficiencies for methanol-water mixtures as a function of liquid composition on the plate. Circles represent experimental values obtained in 13-in. diam. column at total reflux at open slot velocity of 13.3 ft./sec. under 1.0 and 4.4 atm. total pressure. Solid lines represent values predicted by Equation (2) from atmospheric single film data of this paper.

dilution since the entire correction proved to be quite small.

The single film values of N_L were corrected in exactly the same manner by the ratio of the liquid phase Schmidt groups raised to the ⅔ power. Some question exists as to whether the exponent should be ½, but the literature data are not too clear, and the resulting change would not have been appreciable. In the evaluation of the Schmidt groups, viscosities of the pure liquids and of mixtures were obtained from the International Critical Tables (*11*) and extrapolated to higher temperatures where necessary by the method of Perry and Smith (*15*). Liquid densities were obtained from the International Critical Tables and from Perry (*14*) and extrapolated graphically where necessary. Liquid diffusivities at infinite dilution were taken from Wilkie (*19*) and extended to higher temperatures by his method. The effect of concentration upon liquid diffusivity was calculated from the equation by Powell *et al.* (*16*). The resulting value of the Schmidt group for the liquid water-oxygen system at temperatures and pressures employed in the single film studies was 3.76×10^2. The Schmidt group for liquid mixtures of methanol and water at 100° C. was $46. \times 10^2$ at low methanol concentrations, and $18. \times 10^2$ at high methanol concentrations; at 40 mole % methanol the Schmidt group reached a maximum value of $156. \times 10^2$. Temperature also caused an appreciable variation in this function which changed as much as four-fold between 150 and 300° F.. The effect of pressure appeared mainly in its effect upon the boiling temperature of the liquid, and was not an important factor affecting the Schmidt group. The effect of differences in physical properties upon N_L was thus much greater than their effect upon N_G.

The values of N_G and N_L for the methanol-water system were combined to give the local plate efficiency by the following relationship (*4*):

$$\frac{1}{-2.3 \log (1 - E_{OG})} = \frac{1}{N_G} + \frac{mG/L}{N_L} \qquad (2)$$

In Equation (2), E_{OG} is the fractional local plate efficiency, G/L is the molar gas/liquid flow rate on the plate, and m is the slope of the equilibrium curve evaluated at a point corresponding to the liquid concentration on the plate. Values of E_{OG}, the predicted local plate efficiency, were plotted in Figure 13 as a solid line for comparison with the experimental data. Excellent agreement between predicted and observed values is shown, confirming the prediction methods employed.

It should be pointed out that the predicted *local* efficiencies were compared with the experimental *Murphree* efficiencies in Figure 13. This was done since it was assumed that the liquid on the plate was well mixed at the high vapor rate and low liquid rate employed. Tests at comparable gas and liquid rates were made in the oxygen desorption studies in which a series of liquid samples were withdrawn at various points across the operating tray; these samples showed that complete mixing was achieved. At the much higher liquid rates encountered in extractive distillation, good liquid mixing is not obtained, in which case Murphree efficiencies may be approximated from local efficiencies by the equations of Lewis (*12*).

It is interesting to compare how the relative magnitude of the gas and liquid film resistances changes with liquid concentration for the methanol-water system. At liquid concentrations of 90 mole % methanol, 90% of the resistance to mass transfer is in the gas film, at liquid concentrations of 50 mole % methanol, 80% of the resistance is in the gas film; at 10% methanol, only 55% of the resistance is in the gas film. Thus, for beer stills or stripping columns where the alcohol concentrations are low, liquid film resistance is important, and the factors of plate width and liquid rate should be carefully considered in design.

The effect of increased pressure was small in this case since the same volumetric gas and liquid rates were maintained for both the high and low pressure runs. On the basis of the theory developed above in the single film studies, equivalent volumetric flow rates permit an equivalent amount of mass transfer to take place. The changes in pressure and temperature influenced the slope of the vapor-liquid equilibrium curve and the Schmidt groups only to a small degree, so it is not surprising that the plate efficiency results were nearly the same at 50 lb./sq.in. gauge pressure as at atmospheric pressure

Conclusion

The fundamental factors of plate design and operation were shown to affect gas-film efficiencies and liquid-film efficiencies in an entirely different manner, emphasizing the importance of separating over-all efficiencies into their gas- and liquid-phase components for purposes of correlation, prediction, or extension of results. Combination of single-film efficiencies to predict over-all efficiencies was shown to be quite accurate for a binary system for which the physical properties at distillation temperatures and pressures are known. This good agreement offers much encouragement for use of the proposed methods for generalized efficiency prediction, but the need for more work along these lines to evaluate other plate designs and other systems must be emphasized.

Acknowledgments

Most of the experimental portions of this paper were carried out under the Du Pont Fellowship program. Early portions of the single film studies and the experimental studies with the large tray section were sponsored by the Reconstruction Finance Corp., Office of Rubber Reserve, in connection with the government's synthetic rubber program.

Notation

D = diffusion coefficient, sq.ft./hr.

E = plate efficiency

G = molar gas velocity, lb. moles/(hr.)(sq.ft.)

H_L = length of a liquid film transfer unit, ft., computed as Z_H/N_L

L = molar liquid velocity, lb. moles/(hr.)(sq.ft.)

m = slope of equilibrium curve

n = number of gas bubbles in foam

N = number of transfer units

q = volumetric clear liquid flow rate across plate, gal./min.

r = radius of gas bubble, ft.

u = linear vapor velocity, ft./sec.

U' = linear clear liquid velocity across tray based on minimum clear liquid cross section, ft./sec.

Z_f = height of foam on operating tray above tray floor, ft.

Z_H = horizontal distance on the plate in direction of liquid flow over which liquid is contacted with gas, ft.

N_{Sc} = Schmidt number, dimensionless, $\mu/\rho D$

μ = viscosity of gas or liquid, lb./(ft.)(hr.)

ρ = density of gas or liquid, lb./cu.ft.

ϕ = density of foam on operating bubble tray, g./cc.

Subscripts:

G = gas or gas film

L = liquid or liquid film

O = overall

Literature Cited

1. **Bagnoli, E.,** Thesis in Chemical Engineering, Univ. of Delaware, Newark, Del. (1950).
2. Curry, John, Thesis in Chemical Engineering, Univ. of Delaware, Newark, Del. (1950).
3. Davies, J. A., *Ind. Eng. Chem.*, **39**, 774 (1947).
4. Gerster, J. A., Colburn, A. P., Bonnet, W. E., Carmody, T. W., *Chem. Eng. Progress*, **45**, 716 (1949).
5. Gilliland, E. R., *Ind. Eng. Chem.*, **26**, 681 (1934).
6. Good, A. J., Hutchinson, M. H., and Rousseau, W. C., *Ind. Eng. Chem.*, **34**, 1445 (1942).
7. Griswold, J., private communication (1948).
8. Grohse, E. W., Hauer, H. J., McCartney, R. F., Gerster, J. A., and Colburn, A. P., *Chem. Eng. Progress*, **45**, 725 (1949).
9. Happel, J., *et al.*, *Trans. Am. Inst. Chem. Engrs.*, **42**, 189 (1946).
10. Higbie, R., *Trans. Am. Inst. Chem. Engrs.*, **31**, 365 (1935).
11. International Critical Tables, **3**, 257 (1929).
12. Lewis, W. K., Jr., *Ind. Eng. Chem.*, **28**, 399 (1936).
13. Marshall, W. R., and Pigford, R. L., "Application of Differential Equations to Chemical Engineering Problems," 1st Ed., Univ. of Delaware, Newark, Del. (1947).
14. Perry, J. H., "Chemical Engineers' Handbook," 2nd Ed., McGraw-Hill Book Co., New York (1941).
15. Perry, J. H., and Smith, E. R., *Ind. Eng. Chem.*, **25**, 195 (1933).
16. Powell, R. E., Roseveare, W. E., and Eyring, H., *Ind. Eng. Chem.*, **33**, 430 (1941).
17. Scheibel, E. G., personal communication (May, 1951).
18. Van Krevelen, D. W., and Hoftijzer, P. J., *Chem. Eng. Progress*, **46**, 29 (1950).
19. Wilke, C. R., *Chem. Eng. Progress*, **45**, 218 (1949).

Discussion

C. S. Carlson (Standard Oil Development Co., Elizabeth, N. J.): I notice you worked over quite a range of variables. How close was that to ultimate limiting operating capacity of your experimental trays?

J. A. Gerster: We were working with rather high liquid rates, especially because we were interested in the application of the results to extractive distillation where large liquid loads are encountered due to the presence of the solvent. We did not run the gas rate up to especially high values.

G. S. Houghland (M. W. Kellogg Co., New York, N. Y.): What was the criterion of froth height and how was it measured because in some types of trays I have observed that the froth height is rather indefinite; also is there any information on the effect of the vapor density upon the froth height.

J. A. Gerster: Froth heights were measured visually since we were working with air-water systems at atmospheric pressure. We used a column wall which was made of transparent plastic and probably got precision to within the nearest ½ in. We have no data on the effect of pressure or the effect of a different density of gas upon foam height. The results which were obtained at atmospheric pressure were used successfully, however, to predict the methanol-water results at 4.4 atm. total presure.

J. F. Middleton (Foster-Wheeler Corp., New York): The paper of Professor Gerster and associates presents a valuable study of bubble-tray phenomena which, in general, agrees with and, for the first time, provides quantitative values for many of the ideas formulated qualitatively by process engineers in the course of experience in distillation work. Perhaps the only case in which this general statement does not hold precisely is in connection with the authors' interpretation of Figure 3, which gives the relationship between froth density and vapor velocity. The authors attribute the difference between curves *A* and *B* on Figure 3, to the fact that the values of curve *A* were observed on large bubble caps and those of curve *B* on small caps, and therefore the conclusion is reached that the froth density is a function of the size of the caps.

If this were so, then it would be reasonable to expect that somewhat similar differences would occur between curves *C* and *B*, *D* and *B* and even between *C* and *D*. This follows because the basic difference between the large caps and the small caps lies in the number of vapor streams per unit of tray area which can issue simultaneously from each, and if the small caps provide more of these streams than the large caps, the sieve trays similarly provide more streams of vapor than the small caps. In spite of the differences in the number of streams of vapor involved in the observations of curves *B*, *C*, and *D*, there is little difference in the corresponding froth densities, at least between vapor velocities of about 1.3 and 2.8 ft./sec. and, therefore, the difference in the size of the caps cannot be the explanation of the differences between curves *A* and *B*.

One variable which happens to remain constant in the cases of curves *B*, *C*, and *D* is the diameter of the tray and this leads to the thought that the variable which should properly be associated with the froth density to explain the difference between curves *A* and *B* is the hold-up of liquid per unit of area of the tray, which is undoubtedly greater on the tray from which curve *A* was derived than on any of the others. Confirmation of this hypothesis appears to be indicated by the trends followed by all the curves plotted on Figure 3. Each one appears to approach an asymptote at a minimum froth density of about 0.25 g./ml., although curve *A* cannot reach that level until some value of vapor velocity outside the range of the plot is attained. It seems reasonable to expect that a bubbling system, such as that under discussion, should reach an equilibrium density at some minimum value at least over a small range of vapor velocity and, if this is so, it follows that different amounts of liquid hold-up on the tray will need different vapor velocities to make a foam of minimum density. Hence, if it had been possible to continue the experiments of curve *A* to a higher value of vapor velocity, it is probable that the froth density in that case would ultimately have reached the same level as those obtained in the cases of curves *B*, *C*, and *D*.

A possibility exists that an increase of vapor velocity sufficient to give the minimum froth density for curve *A* might be high enough to cause the values for the other three curves to increase again above the minimum. This would probably occur when individual slot velocities became so high that the vapor would merely blow through the liquid in homogeneous streams without mixing. However, this possibility does not invalidate the thesis that the differences at identical vapor velocities between the froth densities for curves *A* and *B* of Figure 3 are due to the difference in liquid holdup on the respective trays; it merely shows that the trays in question have different optimum operating ranges.

J. A. Gerster: Your conclusions appear valid, and it will be interesting to determine if further tests can verify them. We cannot at present predict values of foam density from the tray layout. Robinson and Gilliland (*1*) report a minimum value of froth density of "approximately one-third" for a large bubble tray, which lends weight to your conclusions.

Literature Cited

1. Robinson, C. S., and Gilliland, E. R., "Elements of Fractional Distillation," 4th ed., p. 415. McGraw-Hill Book Co., New York (1950).

(Presented at Forty-third Annual Meeting, Columbus (Ohio).

(The End)

DIFFUSION RATES IN EXTRACTION OF POROUS SOLIDS

II. TWO-PHASE EXTRACTIONS

EDGAR L. PIRET, R. A. EBEL †, C. T. KIANG ‡, and W. P. ARMSTRONG §

University of Minnesota, Minneapolis, Minnesota

Diffusion rates in porous solids are of chemical engineering importance in leaching or extraction operations, in product formation rates in porous catalysts, and in transfer processes through porous membranes or walls.

A previously presented investigation (*14*) of the rates of extraction or diffusion of soluble materials from capillaries, porous slabs and spheres in the unsteady state, has been extended from single-phase to two-phase systems. In these new systems a soluble solid or liquid phase is being progressively extracted or leached by another liquid or gas phase from the interstices of a porous insoluble solid. The soluble solid or liquid, while uniformly distributed, need not completely fill the voids of the porous insoluble solid. The equations developed herein relate the concentration at any point within the porous solid or, if one wishes, the position of the solid-liquid interface or the percentage extraction to the time of extraction.

These very general equations take into account such factors as the porosity of the inert solid and of the soluble material; the length or diameter of the capillary, slab, or sphere; the diffusivity; the average concentration of the surrounding fluid; the retarding effect of the inert porous structure; the solubility of the solid or liquid; the velocity of the solvent at any point in diffusion path relative to the capillary wall; and the density of the solid solute.

A convenient method of measuring integral diffusivities for soluble solids diffusing into any concentration level of solution was developed. This method uses a capillary filled with the powdered solid and follows the rate of fall of the level of the powdered solid as it dissolves and diffuses into a stream flowing across the top of the capillary. Diffusivity data at high concentrations are generally unavailable but are particularly important in industrial processes.

Experimental measurements on single, straight capillaries and on porous alumina spheres were used to verify and demonstrate the application of the equations. An example is given where interfacial tension materially affects the rate of extraction. Integral diffusivities from saturated interfaces were measured in this work for sodium chloride, potassium chloride, copper sulfate, potassium chromate, cadmium iodide, sucrose and water-saturated phenol.

The use of a pore-shape factor to characterize the retarding effect of the porous structure of the inert solid which has been previously proposed for single-phase extractions was here shown to be applicable also to two-phase systems.

APPLICATIONS of diffusion processes in porous solids have been discussed in Part I of this paper (*14*). These include extraction operations, diffusion rates in porous catalytic solids, and transfer operations through porous walls. In Part I theoretical rate equations were developed for the case of single-phase extractions from porous spheres in batch, countercurrent and parallel operations. The validity of the equations was demonstrated by experiments carried out under various conditions with aqueous solutions of several salts and these were extracted from smooth capillaries, tubes filled with fine beads, and porous alumina spheres. The term pore-shape factor was introduced to account for the retarding effect of the tortuous paths, constrictions and enlargements of the inert porous solid on the rate of extraction. This factor can be defined as the ratio of the actual to the theoretical time for extraction.

The investigation is here extended to the case of the batch extraction of two-phase systems. These consist of an inert, porous insoluble carrier solid, a solvent, and a soluble substance present within the carrier solid as a separate liquid or solid phase. As extraction proceeds, the solute-solvent interface recedes into the porous solid.

Two-phase extraction has been applied industrially in the leaching of soda ash from black ash, nitrate from Chilean caliche, copper from low grade ore, and gold from gold-silver alloy ores. Of the application of leaching to metallurgy it has been stated that the method has become extremely important in recent years because of the depletion of rich ores. In 1938 one tenth of the copper, one fourth of the zinc, one half of the gold, and three fourths of the cadmium produced in the United States were recovered by methods involving leaching (*11, 15*).

Other than the works of Sullivan (*16*) on copper ores and of others on rates of evaporation of liquids in capillaries (*7*) there is little available in the literature on the theory of diffusion in two-phase extraction systems. The interesting case where molecules of a diffusing substance react with the medium into which they diffuse has been recently treated by J. J. Hermans (*6*).

In this paper precise theoretical equations will first be carefully developed for two-phase extractions from smooth capillaries. A simple approximate equation will also be obtained. These will then be compared by computation and by experiment. Experimental data for a variety of substances will be shown to verify the equations and the best available data from the literature.

This is Part II of a two-part paper. Part I was published in the August issue of C.E.P.

† Present address: Carbide and Carbon Chemical Corp., Oak Ridge, Tenn.

‡ Present address: Shanghai, China.

§ Present address: Washington University, St. Louis, Mo.

Two-Phase Extractions from Capillaries

A method was developed based on previous experiments by Montillon and Mitchell (*10*) to follow the extraction of a soluble solid from a capillary. Straight, smooth, vertical capillaries filled with two-phase constituents, usually a finely divided solid solute and its saturated solution, were extracted continuously with distilled water flowing past the open end of the capillary. Extraction distances from the open end of the capillary to the developed interface were read with a cathetometer at a known time. Sharp, level interfaces between the solids and solutions occurred, so that accurate measurements could be made.

It had been found advantageous to fill the capillaries with a finely divided solid rather than with a fused solid, because the latter on cooling was found generally to leave voids which were irregular in position and size and which caused uncertainties in the experimental results. The use of a powdered solid with the interstices filled with saturated solution was simple to use, was generally applicable, but did require that the equation developed take this as well as the other factors into account. The hitherto unavailable accurate fundamental equation was developed as follows:

Theoretical Equations for Diffusion of Two-Phase Solutes from Capillary Tubes. The following derivation is for the case of two-phase diffusion from a capillary to an infinite reservoir. Consider a straight, smooth capillary of unit cross-sectional area and finite length. The capillary is initially filled with a uniform mixture of solid solute and its saturated solution. The fraction of the capillary volume occupied by solid solute is α, that occupied by saturated solution is $(1-\alpha)$. One end of the capillary is placed in a flowing stream of solvent of concentration C_0.

Diffusion begins the instant the capillary entrance is brought in contact with the solvent. An interface develops which recedes into the capillary as diffusion proceeds. As the solid dissolves, a hydrodynamic flow of solvent into the capillary occurs. This is a case of forced diffusion and is shown diagrammatically in Figure 1.

The capillary in Figure 1 may be divided into three zones. Zone 1 is composed of fraction α solute and $(1-\alpha)$ saturated solvent by volume; zone 2 a solution, solvent of which came from the solute bed, and zone 3 a solution of which solvent came from the infinite reservoir.

Zones 2 and 3 can be pictured arising as follows: If the solute-solvent interface recedes a distance β then $\alpha\beta$ cc. of solid solute disappears, $(1-\alpha)\beta$ cc. of

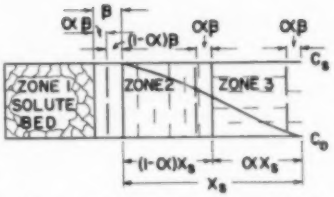


Fig. 1. Dimensions of zones formed in diffusion of a two-phase solute from a finite tube to an infinite reservoir.

saturated solution remains, and $\alpha\beta$ cc. of solvent flows into the capillary. The $(1-\alpha)\beta$ cc. of solution becomes a part of zone (*2*) and $\alpha\beta$ cc. of solvent becomes part of zone 3. If the extraction distance is x_s cm. then zone 2, by a volume balance, is $(1-\alpha)x_s$ cc. or $(1-\alpha)x_s$ cm. in length.

By the above reasoning it is also clear that all solvent in the diffusion path is at rest with respect to the boundary between zones 2 and 3. Fick's Law may be written with reference to the zone 2-zone 3 boundary

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (1)$$

In zone 3 the concentration at any point with reference to the zone 2-zone 3 boundary is obviously greater than that in the infinite reservoir. Since all solvent in zone 3 came from the reservoir the concentration at any point must be increasing with time. That is, $\partial C/\partial t$ is a positive function. By Equation (1) $\partial^2 C/\partial x^2$ is a positive function. Therefore, the curve of concentration vs. distance in zone 3 is concave upward. Similarly, in zone 2 the concentration at any point is less than the concentration of saturated solvent in the solute bed. Since the solvent in zone 2 came from the solute bed, the concentration change with respect to time at any point must be negative, that is, $\partial C/\partial t$ is a negative function. Therefore, the curve of concentration vs. distance in zone 2 is concave downward. Moreover, because $\partial^2 C/\partial x^2$ is positive in zone 3 and negative in zone 2, the point of inflection must lie on the zone 2-zone 3 boundary.

It is desired in the following to develop an equation, (*3*), for the rate at which the interface moves relative to the capillary entrance. Now, relative to the diffusion media, solute moves from the interface to the right in Figure 1 by diffusion at a rate

$$P = -D\left(\frac{\partial C}{\partial x}\right)_i$$

where P is the quantity of solute per unit area per unit time leaving the interface by diffusion and $(\partial C/\partial x)_i$ is the concentration gradient at the interface.

Since solvent flows to the left relative to the capillary entrance, it carries solute toward the interface. If v^* is the velocity of water at the interface, relative to the capillary entrance, then Q, the quantity of solute per unit area per unit time carried to the interface by flow, is equal to $v^* C_s$, and the overall rate of solute leaving the interface is

$$B = -D\left(\frac{\partial C}{\partial x}\right)_i - v^* C_s \qquad (2)$$

B is directly related to the rate at which the interface moves. In Figure 2, at time t the interface is at point x_s; at time $t+\Delta t$ the interface is at point $x_s+\Delta x_s$. For the interface to move a distance Δx_s, a quantity of solute equal to $+(\rho_a - C_s)\Delta x_s$ must leave the interface. Therefore,

$$B_{av}\Delta t = +(\rho_a - C_s)\Delta x_s$$

ρ_a = apparent density of solute bed

$$= \frac{\text{g. salt}}{\text{cc. bed volume}}$$

$$\left(\frac{dx_s}{dt}\right) = +\frac{B}{(\rho_a - C_s)}$$

B_{av} = avg. rate of solute leaving interface between x_s and $x_s+\Delta x_s$ from time t to $t+\Delta t$

Evaluating B from Equation (*2*) there results

$$\left(\frac{dx_s}{dt}\right) = \frac{-D}{\rho_a - C_s}\left(\frac{\partial C}{\partial x}\right)_i - \frac{v^* C_s}{\rho_a - C_s}$$

v^* may be eliminated by noting that the flow of solvent at the interface is equal to the product of α and the linear velocity of the interface,

$$v^* = \alpha\left(\frac{dx_s}{dt}\right),$$

$$\frac{dx_s}{dt} = \frac{-D}{\rho_a - (1-\alpha)C_s}\left(\frac{\partial C}{\partial x}\right)_i \qquad (3)$$

The conditions of the problem that must be satisfied by a solution are:

1. With the point of inflection as the origin of the reference frame the governing equation in the diffusion path must be:
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$
2. At the capillary entrance the concentration must be C_s for all $t > 0$.
3. At the solute-solvent interface the concentration must be C_s for all $t > 0$.
4. A point of inflection must occur at a distance αx_s from the capillary entrance.

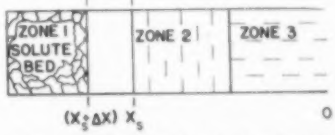


Fig. 2. Location of interface developed at time t and $t+\Delta t$ in the diffusion of a two-phase solute from a finite tube to an infinite reservoir.

5. The velocity of the interface relative to the capillary entrance and the concentration gradient at the interface must be related by Equation (3).

The solution to the case of single-phase diffusion from an initially sharp boundary in a column extending infinitely far in both directions is well known (*1*), that is:

$$C = \frac{1}{2\sqrt{\pi Dt}} \int_{-\infty}^{\infty} f(\mu)\, exp - \left(\frac{\mu - x}{2\sqrt{Dt}}\right)^2 d\mu \qquad (4)$$

where $f(\mu) = C_s$ for $x < 0$ and $f(\mu) = C_o$ for $x > 0$ for this case. Now it will be demonstrated here that an exact solution for the present problem of a receding solid interface can be obtained from Equation (4) by having $f(\mu) = M + s + C_o$ for $x < 0$ and $f(\mu) = -M + s + C_o$ for $x > 0$. Note that this solution satisfies condition 1 where x refers to the distance from the point of inflection.

For clarity, a diagram of the conventional solution is given in Figure 3 and a diagram of the modified solution in Figure 4. C_s is the initial concentration ($t = 0$) in the conventional capillary (Fig. 3), for all $x < 0$. However, the initial concentration is obviously greater than C_s in a capillary filled with solid solute. M, an arbitrary constant, is introduced to account for this high space concentration and provides a means for "spreading the curve." Point A, Figure 4, then represents the interface and is the intersection of the concentration curve with the horizontal line C_s. Similarly, point B (Fig. 4), represents the capillary entrance and is located by the intersection of the concentrated curve and horizontal line C_o. The diffusion path is the horizontal distance from A to B. This arrangement insures that the concentration at the interface will always be C_s and that at the capillary entrance C_o. Thus conditions 2 and 3 are satisfied.

As the fractional volume of solid solute, a, varies, the point of inflection is located at relatively different distances from the capillary entrance. To control the position of the point of inflection, a constant s is introduced as follows. Substituting the above modified $f(\mu)$ in Equation (4) and rearranging, there results:

$$\frac{x}{2\sqrt{Dt}} = \psi^* \left[\frac{s + C_o - C}{M}\right] \qquad (5)$$

where ψ^* is the inverse of the error function

$$\frac{1}{\sqrt{\pi Dt}} \int_o^x exp - \left(\frac{x - \mu}{2\sqrt{Dt}}\right)^2 d\mu.$$

The capillary entrance is a distance ax_s from the point of inflection and the concentration there is C_o, therefore:

$$\frac{ax_s}{2\sqrt{Dt}} = \psi^* \left[\frac{s}{M}\right] \qquad (6)$$

Similarly, the interface is a distance $-(1-a)x_s$ from the point of inflection and the concentration is C_s, and as above

$$\frac{(1-a)x_s}{2\sqrt{Dt}} = \psi^* \left[\frac{\Delta C - s}{M}\right] \qquad (7)$$

Writing the identity

$$\frac{ax_s}{ax_s + (1-a)x_s} = a$$

and replacing the terms on the left side by their equivalents from (6) and (7), one obtains

$$a = \frac{\psi^*\left(\frac{s}{M}\right)}{\psi^*\left(\frac{s}{M}\right) + \psi^*\left(\frac{\Delta C - s}{M}\right)} \qquad (8)$$

For any positive value of M, a value s can be selected to satisfy Equation (8), and as a consequence satisfy condition 4.

The rate at which point A moves with respect to point B (Fig. 4) is obviously

$$\frac{dx_s}{dt} = \frac{d(ax_s)}{dt} + \frac{d(1-a)x_s}{dt} \qquad (9)$$

The right-hand members of Equation (9) can be found by taking the derivatives with respect to time of Equations (6) and (7).

$$\frac{dx_s}{dt} = \sqrt{\frac{D}{t}} \left[\psi^*\left(\frac{\Delta C - s}{M}\right) + \psi^*\left(\frac{s}{M}\right)\right] \qquad (10)$$

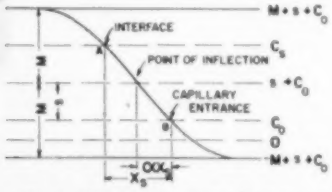


Fig. 4. Adaption of conventional solution of free diffusion in an infinite tube to the case of diffusion of a two-phase solute from a finite tube to an infinite reservoir.

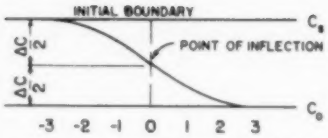


Fig. 3. Conventional solution of free diffusion from an initially sharp boundary in an infinite tube.

From Equation (4) the slope at any point in the diffusion path can be calculated

$$\left(\frac{\partial C}{\partial x}\right) = -\frac{M}{\sqrt{\pi Dt}} exp\left[-\frac{x^2}{4Dt}\right] \qquad (11)$$

At the interface since $x = -(1-a)x_s$

$$\left(\frac{\partial C}{\partial x}\right)_i = -\frac{M}{\sqrt{\pi Dt}} exp\left[-\frac{(1-a)^2 x_s^2}{4Dt}\right] \qquad (12)$$

but from Equation (7)

$$\frac{(1-a)x_s}{2\sqrt{Dt}} = \psi^*\left[\frac{\Delta C - s}{M}\right]$$

Therefore,

$$\left(\frac{\partial C}{\partial x}\right)_i = -\frac{M}{\sqrt{\pi Dt}} exp\left[-\left(\psi^*\frac{\Delta C - s}{M}\right)^2\right] \qquad (13)$$

Using Equations (10) and (13) to replace dx_s/dt and $(\partial C/\partial x)_i$ in Equation (3)

$$\psi^*\left(\frac{s}{M}\right) + \psi^*\left[\frac{\Delta C - s}{M}\right] = \frac{M}{\sqrt{\pi(\rho_s - (1-a)C_s)}} exp - \left[\psi^*\left(\frac{\Delta C - s}{M}\right)\right]^2 \qquad (14)$$

For any positive value of s, a value of M can be found to satisfy Equation (14) which in turn guarantees that condition 5 is satisfied.

The desired relationship between x_s and t can be obtained from Equation (6) or (7), choosing the former

$$x_s = \frac{2\sqrt{Dt}}{a} \psi^*\left(\frac{s}{M}\right) \qquad (15)$$

where s and M are obtained by a solution of Equations (8) and (14).

Thus, by Equation (15) the distance of recession of the solid can be found exactly as a function of time and the physical properties of the system.

The following numerical example will show the method of using these equations.

Data Run of *C*-3

$C_s = 0.3171$ g. NaCl/cc H_2O
$C_o = 0$
$\Delta C = 0.3171$ g. NaCl/cc
$\rho_s = 1.458$ g. NaCl/cc
$a = 0.642$ fractional volume of solid solute in the solid bed

$$\sqrt{\pi[\rho_s - (1-a)C_s]} = 2.383$$

Estimate $s = aC_s = 0.2030$
By trial and error, solve Equation (14) for M.
Let $M = 0.860$

$$S/M = 0.2360;$$

$$\psi^*\left(\frac{s}{M}\right) = 0.2123$$

$$\frac{\Delta C - s}{M} = 0.1327;$$

$$\psi^*\left(\frac{\Delta C - s}{M}\right) = 0.1181;$$

$$\left[\psi^*\left(\frac{\Delta C - s}{M}\right)\right]^2 = 0.0139$$

$$\psi^*\left(\frac{s}{M}\right) + \psi^*\left(\frac{\Delta C - s}{M}\right) = 0.3304$$

$$\frac{M}{\sqrt{\pi(\rho_o - (1-a)C_s)}}\,exp - \left[\psi^*\left(\frac{\Delta C - s}{M}\right)\right]^2 = \frac{0.9862 \times .860}{2.383} = 0.3558$$

which is a little high; try

$$M = 0.8310$$

$$s/M = 0.2443;$$

$$\psi^*\left(\frac{s}{M}\right) = 0.2200$$

$$\left(\frac{\Delta C - s}{M}\right) = 0.1373;$$

$$\psi^*\left(\frac{\Delta C - s}{M}\right) = 0.1223;$$

$$\left[\psi^*\left(\frac{\Delta C - s}{M}\right)\right]^2 = 0.0149$$

$$\psi^*\left(\frac{s}{M}\right) + \psi^*\left(\frac{\Delta C - s}{M}\right) = 0.3428$$

$$\frac{M}{\sqrt{\pi(\rho_o - (1-a)C_s)}}\,exp - \left[\psi^*\left(\frac{\Delta C - s}{M}\right)\right]^2 = 0.3428$$

The two sides of Equation (14) now check exactly.

Calculate a from Equation (8) to see if it agrees with 0.642.

$$\frac{\psi^*\left(\frac{s}{M}\right)}{\psi^*\left(\frac{s}{M}\right) + \psi^*\left(\frac{\Delta C - s}{M}\right)} = \frac{0.2200}{0.3428} = 0.641$$

Therefore, the estimate of s was sufficiently accurate. Equation (15) becomes for this case

$$x_a = 0.686\sqrt{Dt} \qquad (16)$$

This equation may now be used to calculate for this system the diffusivity, D, from measurements of distances, x_a, as a function of time, t; or conversely, if one knows the diffusivity of the system, the penetration into a capillary may be computed as a function of time.

Approximate Solution and Comparison with the Exact Equation. An approximate solution can be obtained by assuming a linear concentration distribution in the capillary and using Equation (3). This solution assumes that the portion of the curve between horizontal lines C_o and C_s is a straight line (Fig. 4).

$$\left(\frac{\partial C}{\partial x}\right)_t = \frac{-\Delta C}{x_a}$$

$$\frac{dx_a}{dt} = \frac{D}{\rho_o - (1-a)C_s}\left(\frac{\Delta C}{x_a}\right)$$

Integration from $x_a = 0$ to x_a and from $t = 0$ to t gives,

$$\frac{x_a^2}{2Dt} = \frac{\Delta C}{\rho_o - (1-a)C_s} \qquad (17)$$

These two equations, (15) and (17), were then tested experimentally.

Equation (15) should be valid for any values of the basic variables ρ_t, C_s, D and a, providing $\rho_t > C_s$ and $a > 0$. If ρ_t is equal to C_s only one phase is present in the capillary. The solute and solvent are completely miscible and Equation (4) applies. If a is zero only one phase is present. The solute is a saturated solution and again Equation (4) governs the extraction.

Equation (17), while convenient to use, is an approximate solution and must be compared with Equation (15) to determine its range of accuracy. It is convenient to consider the ratio C_s/ρ_t as characterizing the solubility of a material involved in a two-phase system. When the ratio is near one, the material is almost completely miscible with the solvent. When the ratio is close to zero, the material is nearly insoluble in the solvent. In Figure 5 lines of constant per cent difference between the diffusivities calculated by each equation for sucrose, potassium chromate, and copper sulphate have been plotted with the ratio C_s/ρ_t as the ordinate and a as the abscissa. The phase boundaries at C_s/ρ_t equal to one and a equal to zero are shown as dotted lines. At a equal to one positive discrepancies exist between the diffusivities calculated by the two equations which increase with the ratio C_s/ρ_t. When a is about 0.7 the diffusivities from the equations are very close. Near the boundary a equals zero, negative divergence occurs that increases with the ratio C_s/ρ_t.

It is significant that in systematic arrangements of identical spheres the value of a varies from 0.74 for the closest packing to 0.52 for the most open type. Also in beds of several natural materials of graded particle size a was found to vary from 0.65 to 0.56 (*5*). Thus it appears that the range $a = 0.6$ to 0.7 is likely to be encountered in practice in which range the approximate equation can be used with negligible error.

Apparatus and Procedure. A precision tube capillary 0.102 cm. in diam. and about 2.5 cm. in length was loaded as follows: The solid was ground to pass a 200-mesh screen. One end of the capillary was covered with a cloth filter and connected to a 12 mm. Hg. vacuum. A small increment (about 2 mg.) of the powder was introduced into the capillary and tamped with a close-fitting steel mandrel. This process was continued until the capillary was filled. The capillary was then placed in a flask, submitted to a 2 mm. Hg vacuum, or less, and then covered with a saturated solution of the solid. Upon releasing the vacuum, saturated solution was forced into the solid interstices formerly occupied by air. The ends were temporarily sealed with tape. The density of loading was calculated from the initial weight of the capillary, the sealing strips, and the weights after each operation.

The apparatus is shown diagrammatically in Figure 6. In normal operation water flowed from reservoir A, through preheater B, into extraction tube C, and thence to drain E. The level of the solid in the capillary (which moves downward as diffusion proceeds) was measured with reference to the capillary entrance by a cathometer. To reduce the effects of stagnant water at the capillary entrance, the capillaries were ground as shown in Figure 7. To start a run, reservoir flow was stopped at point 2 (Fig. 6), thermometer D was removed, and extraction tube C drained. One tape seal was removed, and the capil-

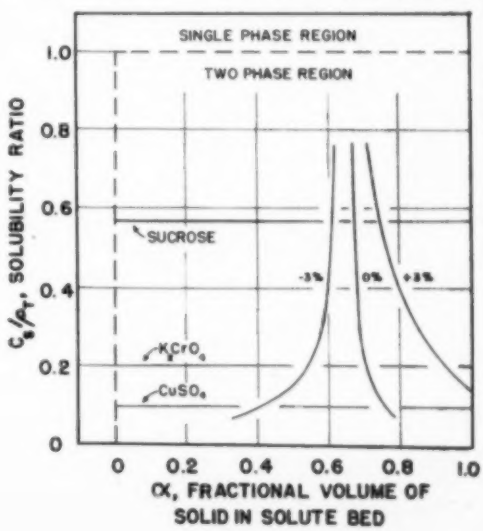


Fig. 5. Comparison of Equations (15) and (17).

TABLE 1.—TWO-PHASE

Extraction

Material	NaCl		KCl		Sucrose		CdI_2		Sucrose	
Run No.	C-3		C-5		C-22		C-23		C-24	
ρ_{so}, g./cc.	1.458		1.232		1.564		4.182		1.323	
	0.643		0.550		0.678		0.701		0.612	
	t, min.	x_0, cm.	t, min.	x_0, cm.	t, min.	x_0, cm.	t, min.	x_0, cm.	t, min.	x_0, cm.
Temp. = 25° C.	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
Outside Conc. = 0	10	0.060	10	0.075	10	0.050	10	0.050	14	0.065
	20	0.080	25	0.125	20	0.078	20	0.073	24	0.080
	30	0.100	31	0.138	30	0.093	30	0.085	33	0.110
	45	0.130	40	0.154	50	0.115	50	0.110	55	0.133
	62	0.150	60	0.195	87	0.147	82	0.139	85	0.175
	95	0.188	100	0.255	120	0.180	120	0.163	130	0.217
	231	0.303	150	0.315	152	0.210	180	0.200	204	0.267
	250	0.318	180	0.350	240	0.258	300	0.260	358	0.336
	312	0.356	200	0.370	417	0.349	400	0.302	605	0.455
	360	0.384	420	0.540	678	0.452	625	0.370	930	0.528
	950	0.649	450	0.557	1070	0.558	1164	0.490	1490	0.655
	1010	0.669	1000	0.832	1334	0.622	1418	0.538		
	1060	0.684	1050	0.857	1527	0.644	1425	0.547		
	1110	0.694	1800	1.132	1983	0.767	1680	0.585		
	1440	0.796	2620	1.368	2510	0.858	1897	0.620		
	1465	0.803	2800	1.420			2483	0.706		
	1650	0.851					2776	0.762		
	1700	0.862								
	2440	1.034								
	2500	1.045								
	2900	1.125								
	3100	1.167								
	3860	1.300								
	3900	1.310								

* Density of phenol saturated with water, g./cc.
** Density of water saturated with phenol, g./cc.

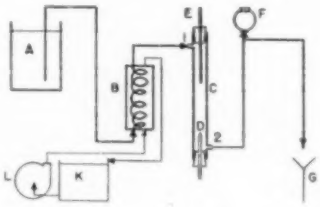


Fig. 6. Apparatus for extraction of a solid solute from a capillary. ►

KEY

A RESERVOIR
B HEAT EXCHANGER
C EXTRACTION TUBE
D CAPILLARY
E THERMOMETER
F SEPARATORY FUNNEL
G DRAIN
H RUBBER STOPPER
I GLASS ROD
J SCOTCH TAPE SEAL
K THERMOSTAT
L PUMP

lary placed plumb in extraction tube *C*. Water was introduced at point *2*; at zero time the water crossed the capillary tip. When the extraction tube was filled, the thermometer was replaced, and the flow of water reversed.

Experiments on Two-Phase Systems in Capillary Tubes. The primary objectives of the two-phase capillary experiments were to obtain diffusivity data and to test the derived equations experimentally. A number of materials were used. Unfortunately no integral diffusivities with ranges from saturated solution to pure water have been reported in the literature. Values with which to compare the results obtained had to be estimated by extrapolation of literature diffusivities.

Results of these experiments are listed in Table 2. The variation of the ratio C_s/ρ_t was from 0.098 for copper sulfate to 0.57 for sucrose. The range of a was from 0.550 for potassium chloride to 0.727 for potassium chromate. The agreement between the estimated integral diffusivities from the literature and those obtained experimentally is very good. For the range of a investigated the approximate and exact equations yield very close results. In the duplicate sucrose runs better agreement is obtained using Equation (15) for calculation of the diffusivities than using (17). Further experiments are necessary to test the effect of a greater range of a. The data are tabulated in Table 1 and plotted in Figure 8.

It can be seen from these data that Equations (15) and (17) are valid for the range of variables studied. Providing two phases are present in a capillary, the variables in Equation (15) have an unlimited range. Equation (17), on the other hand, is limited to materials of a low C_s/ρ_t ratio or to systems in which a is about 0.70.

Two-Phase Extractions from Porous Spheres

Alumina porous spheres were impregnated with solid sodium chloride, potassium chloride, and phenol saturated with water (liquid phase). Batch extractions were performed using distilled water or aqueous solutions of the impregnated material as the solvent. At selected times samples were taken and analyzed to yield data of per cent extraction at the measured time. The objectives of

TABLE 2.—DIFFUSIVITIES FROM TWO-PHASE CAPILLARY EXPERIMENTS

Substance Units	Run No.	C_{sat}	C_s gm./cc.	ρ_{so} gm./cc.	a	Diffusivity $\times 10^5$ sq.cm./sec. Eq. (15)	Diffusivity $\times 10^5$ sq.cm./sec. Eq. (17)	Diffusivity $\times 10^5$ Estimated from Literature sq.cm./sec.
Sucrose	C-22	0.570	0.9043	1.364	0.678	0.288	0.287	† 0.24 McBain & Liu (9)
Sucrose	C-24	0.570	0.9043	1.323	0.612	0.263	0.270	0.26 Oholm (13)
K_2CrO_4	C-30	0.199	0.5436	2.063	0.687	1.16	1.16	* 1.14 Oholm (12) (3N to pure water)
K_2CrO_4	C-31	0.199	0.5436	2.124	0.727	1.17	1.16	† 2.0 McBain & Dawson (8)
KCl	C-5	0.156	0.3110	1.232	0.550	2.09	2.13	
NaCl	C-3	0.147	0.3170	1.458	0.642	1.55	1.56	* 1.50 Burrage (2) (4N to pure water)
CdI_2	C-23	0.130	0.7389	4.182	0.706	1.03	1.03	.....
CdI_2	C-25	0.130	0.7389	4.262	0.714	1.01	1.01	.....
Phenol	C-40	0.117	0.0870	0.7462	0.672	0.793	0.793	0.94 Eyring (4) (0.25% by weight to pure water)
$CuSO_4$	C-37	0.098	0.2239	1.081	0.690	0.499	0.498	‡ 0.56 Eversole (3)
$CuSO_4$	C-38	0.098	0.2239	1.064	0.672	0.504	0.503	

* Corrected for temperature using 0.025 as temp. coeff.
† Extrapolated from low concentrations.
‡ Estimated from differential value.

Data

CdI_2 C-25 4.262 0.714

t min.	x_s cm.
0	0.000
14	0.058
24	0.072
33	0.085
55	0.110
85	0.138
130	0.166
203	0.217
356	0.288
604	0.373
927	0.464
1481	0.568
2046	0.680

K_2CrO_4 C-30 2.063 0.687

t min.	x_s cm.
0	0.000
10	0.060
29	0.100
49	0.130
91	0.193
100	0.206
150	0.257
175	0.277
232	0.327
294	0.360
485	0.445
793	0.559

K_2CrO_4 C-31 2.124 0.727

t min.	x_s cm.
0	0.000
15	0.075
25	0.097
39	0.120
60	0.153
109	0.201
180	0.263
245	0.300
325	0.357
460	0.423
758	0.555
1345	0.698

$CuSO_4$ C-37 1.081 0.690

t min.	x_s cm.
0	0.000
10	0.043
21	0.070
40	0.084
46	0.097
64	0.108
90	0.125
116	0.136
240	0.183
253	0.200
457	0.255
728	0.310
1367	0.425
1993	0.520
2865	0.617
4288	0.745
5855	0.860

$CuSO_4$ C-38 0.672 1.064

t min.	x_s cm.
0	0.000
15	0.065
30	0.084
55	0.102
99	0.129
124	0.146
245	0.195
442	0.255
739	0.320
1386	0.430
2017	0.527
2900	0.630
4313	0.766
5845	0.865

Phenol C-40 1.0462* 1.0045**

t min.	x_s cm.
0	0.000
10	0.045
23	0.095
34	0.110
47	0.120
65	0.135
134	0.178
196	0.197
346	0.242
604	0.298
931	0.359
1297	0.421
1690	0.474
2343	0.559
3135	0.628
3860	0.694
4375	0.726
5375	0.818
6096	0.872
7119	0.935
8482	1.014
9951	1.085
11224	1.162
12668	1.225
14109	1.304
15948	1.371
17248	1.428
18479	1.487
20622	1.577

the experiments were to test derived equations experimentally, to check the applicability of integral diffusivities determined by capillary extractions, and to determine the pore-shape factor of the alumina spheres.

Theoretical Equation. An approximate equation for the two-phase extraction of porous spheres can be obtained that is equivalent to Equation (17) for capillaries. Consider a porous sphere of radius R impregnated with a fraction a by volume of solid solute and fraction $(1-a)$ saturated solution. Diffusion to a finite, agitated reservoir begins at zero time. The solute-solvent interface is at a radius S at time t. Solute is leaving the interface at a rate, B.

$$B = -4\pi S^2 D\left(\frac{\partial C}{\partial r}\right)_i + v^* C_s 4\pi S^2 \qquad (18)$$

where, as before, v^* = velocity of solvent at interface at time t.

When the interface recedes a distance dS, $-(\rho_a - C_s)4\pi S^2 dS$ g. of solute must flow from the interface.

$$Bdt = -(\rho_a - C_s)4\pi S^2 dS \qquad (19)$$

Eliminating B from Equations (18) and (19),

$$\frac{dS}{dt} = \frac{D}{(\rho_a - C_s)}\left(\frac{\partial C}{\partial r}\right)_i - \frac{v^* C_s}{(\rho_a - C_s)} \qquad (20)$$

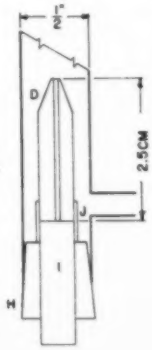


Fig. 7. Capillary mount.

Using the relationship that

$$v^* = a\frac{dS}{dt}$$

Equation (20) becomes

$$\frac{dS}{dt} = \frac{D}{\rho_a - (1-a)C_s}\left(\frac{\partial C}{\partial r}\right)_i \qquad (21)$$

Equation (21) is an expression of the velocity of the interface in terms of the concentration gradient at the interface and the physical properties of the system.

It is now desirable to derive an approximation for the concentration gradient in terms of S and t so that Equation (21) may be integrated. For this derivation two assumptions are required:

1. The concentration in the reservoir, C_s, remains constant during the extraction. This is a justifiable assumption providing the ratio of the volume of solvent in the reservoir to the volume of solution in the porous spheres is large.

2. The actual concentration distribution in the diffusion path at any time is very closely described by a steady state extraction. This assumption is based upon the success of the approximate Equation (17) for capillaries.

The law for radial diffusion is:

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial r^2} + \frac{2\partial C}{r\partial r}\right)$$

But $\partial C/\partial t$ is approximately zero

$$-\frac{d^2C}{dr^2} = \frac{2}{r}\frac{dC}{dr} \qquad (22)$$

Equation (22) is an ordinary differential equation whose solution is

$$C = -\frac{k_1}{r} + k_2$$

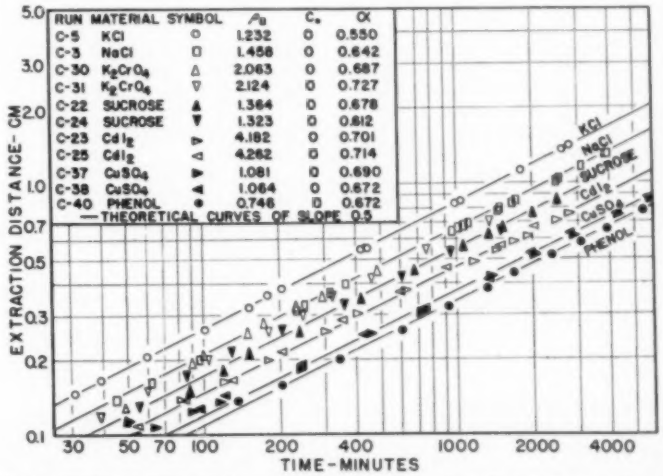


Fig. 8. Extraction of various two-phase solutes from straight smooth capillaries using a continuous stream of distilled water as solvent.

TABLE 3.—TWO-PHASE

Material	NaCl	NaCl	NaCl	NaCl	NaCl
Initial Outside Conc., g./cc.	0	0	0	0	0.0752
Volume Ratio (Solvent to solute)	33	33	29	31	44
Temp.	25° C.	25° C.	25° C.	25° C.	25° C.
Run No.	101	102	103	104	107
Set	A	B	C	D	D

t min.	100-E %	t min.	100-E %	t min.	100-E %	t min.	100-E %	t min.	100-E %
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
5	11.7	5	8.85	5	9.65	5	10.2	6	6.7
20	18.5	20	14.2	20	15.4	20	16.2	22	12.5
82	30.3	80	25.9	80	28.3	80	27.9	81	20.0
152	38.1	150	35.0	132	35.2	130	34.0	200	33.6
255	46.0	250	43.6	225	44.5	220	41.9	451	47.4
550	60.1	550	59.0	525	61.5	520	57.9	690	56.8
1150	74.8	1151	74.9	1125	76.7	1120	71.7	1083	65.2
1780	81.9	1800	83.4	1775	85.2	1770	79.0	1786	73.7
2565	86.3	2560	88.8	2535	90.2	2530	82.5	3540	81.0
4380	90.7	4280	93.8	4360	95.6	4360	89.6	3935	87.2
								5350	88.9
								6830	91.9
								8260	92.6
								9715	93.8
								12917	95.5

Using the conditions that $C = C_0$ at $r = R$, and $C = C_s$ at $r = S$ to evaluate k_1 and k_2,

$$C = \left(\frac{RS}{R-S}\right)\frac{\Delta C}{r} + \frac{SC_s - RC_0}{S-R} \qquad (23)$$

Taking the derivative of Equation (23) with respect to r and evaluating at the interface,

$$\left(\frac{dC}{dr}\right)_i = -\frac{R\Delta C}{(R-S)S}$$

Substituting this value into Equation (21) as an approximation to $(\partial C/\partial r)_i$

$$\frac{dS}{dt} = \frac{-DR}{\rho_0 - (1-\alpha)C_s}\frac{\Delta C}{(R-S)S}$$

Integrating between $r = R$ at $t = 0$ and $r = S$ at $t = t$

$$\left[\frac{1}{6} - \frac{1}{2}\left(\frac{S}{R}\right)^2 + \frac{1}{3}\left(\frac{S}{R}\right)^3\right]\frac{(\rho_0 - (1-\alpha)C_s)}{\Delta C} = \frac{Dt}{R^2} \qquad (24)$$

Equation (24) is the relation of interface radius S and time t in terms of the physical properties of the system. Based on the assumptions above, a relation between per cent unextracted and S is necessary. This can be done as follows:

Let

W_s = quantity of solute in sphere from $r = S$ to $r = R$

then

$$W_s = 4\pi\rho\int_S^R r^2 C dr \qquad (25)$$

and

$$W_s = 4\pi\rho\left[\frac{(R+S)}{2}RS\Delta C + \frac{(-SC+RC)}{3}(R^2+RS+S^2)\right] \qquad (26)$$

Also let

W_d = quantity of solute in sphere of radius S

then

$$W_d = \frac{4}{3}\pi S^3\rho\rho_0 \qquad (27)$$

Let

W_u = quantity of unextractable solute in sphere

then

$$W_u = \frac{4}{3}\pi R^3\rho C_0 \qquad (28)$$

Let

W_t = quantity of extractable solute originally in sphere

then

$$W_t = \frac{4}{3}\pi R^3\rho(\rho_0 - C_0) \qquad (29)$$

E, the per cent of extractable material remaining unextracted, can be expressed by the quantities defined above as,

$$E = \frac{W_s + W_d - W_u}{W_t}100 \qquad (30)$$

Replacing the terms on the right side of Equation (30) by values given in Equations (25) to (30),

$$E = \frac{100}{\rho_0 - C_0}\left[\left(\frac{S}{R}\right)^3(\rho_0 - C_0) + \left(\frac{S}{R}\right)^2\frac{\Delta C}{2} + \frac{S}{R}\frac{\Delta C}{2}\right] \qquad (31)$$

Equations (24) and (31) may be used to calculate values of E and corresponding t values by inserting numbers from zero to one for the ratio S/R. For a given percentage extraction the ratio S/R is fixed and from Equation (24) it can be seen that the group Dt/R^2 becomes equal to a constant. The time to reach a given per cent extraction is therefore inversely proportional to the diffusivity and directly proportional to the sphere radius squared.

The above equations have been derived on the basis of an ideal sphere whose structure offers no resistance to diffusion. We will consider as before (*14*) an actual sphere of radius R to be equivalent to an idealized sphere of radius KR. The square of this constant, K^2, we have called the "pore-shape factor." This factor, K^2, can also be considered as the ratio of the actual to theoretical time for a given per cent extraction. Equation (24) becomes for an actual porous sphere

$$\left[\frac{1}{6} - \frac{1}{2}\left(\frac{S}{R}\right)^2 + \frac{1}{3}\left(\frac{S}{R}\right)^3\right]\frac{(\rho_0 - (1-\alpha)C_s)}{\Delta C} = \frac{Dt}{K^2R^2} \qquad (32)$$

Apparatus and Procedure. The apparatus and procedure for the extraction experiments were the same as for the single-phase batch extractions described previously (*14*). The technique for the impregnation of porous spheres with solid KCl and NaCl consisted in heating in a porcelain crucible a mix of granular salt and the alumina spheres. This heating was done in a vacuum chamber to a temperature above the melting point of the salt. The vacuum attained was 7 mm. or better; upon releasing the vacuum, atmospheric pressure forced the molten salt into the pores of the spheres. Preliminary experiments showed that reactions occurring at the elevated temperatures were negligible and that uniform distribution of solid salt throughout the spheres was obtained. Cleavage of partially extracted spheres showed that, as postulated in deriving Equations (31) and (32), the extraction of the solid occurred uniformly from a spherical shell of increasing thickness.

Experiments. A series of experiments (Figs. 9 and 10, Table 3), on the batch extraction of solid sodium and potassium chloride from porous alumina spheres was made in which the effect of external solution concentration was studied. The material balances checked within 2% or better. The values of per cent extraction vs. time so obtained were compared with those predicted by Equations (31) and (32) (Figs. 9 and 10). The diffusivities used in evaluating the theoretical equation were those obtained in the two-phase capillary experiments. The theoretical equation does not allow for a rising concentration in the external solution, therefore, the average concentration of the extraction solution was

POROUS SPHERE EXPERIMENTS

NaCl 0.1924		KCl 0		KCl 0		KCl 0		KCl 0.1075		KCl 0.2026	
35		34		30		31		35		34	
25° C. 111 D		25° C. 201 C		25° C. 202 B		25° C. 204 C		25° C. 205 B		25° C. 206 B	
t min.	100-E %	t min.	100-E %	t min.	100-E %	t min.	100-E %	t min.	100-E %	t min.	100-E %
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
10	5.3	20	18.4	20	17.2	6	10.9	10	10.6	10	6.4
30	10.0	80	33.1	80	30.2	22	18.0	30	16.3	30	11.8
90	16.5	205	46.6	205	46.1	80	31.3	90	26.9	90	19.4
250	26.8	450	65.4	450	62.5	200	46.1	250	42.9	250	30.7
600	39.2	700	75.2	700	72.1	450	62.7	600	58.3	600	45.3
1320	53.2	1100	83.3	1100	81.1	690	71.3	1320	73.4	1330	61.5
		1800	90.6	1800	87.2	1083	80.1	2580	84.2	2580	74.6
		2600	95.8	2600	91.8	1785	86.2			4020	80.0
				4000	94.4	2535	89.6			5600	85.6
				5530	94.9	3933	92.8			9900	87.6
				6810	95.3	5350	94.3				
				8345	96.6	6830	96.7				
						8258	96.9				
						9725	99.5				

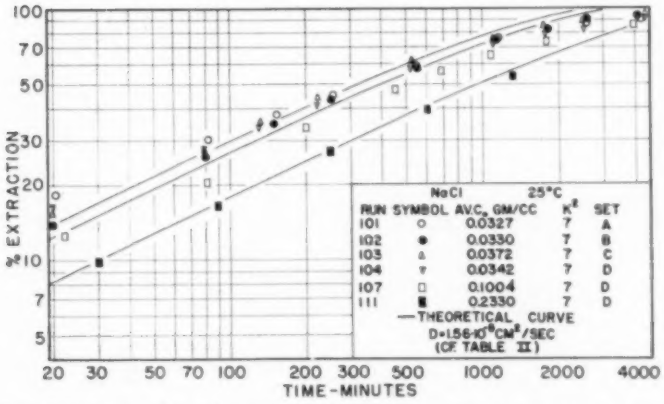


Fig. 9. Extraction of solid NaCl from porous alumina spheres using dilute NaCl solutions as solvent.

used for the calculations. This causes some deviation from the calculated curves near the end of the extractions.

It had been experimentally shown by preliminary experiments that the sets *A*, *B*, *C*, *D* of porous alumina spheres showed identical extraction rates for two-phase extractions of solid sodium chloride. A single-phase extraction of sodium chloride solution (Fig. 11) established a value of K^2 equal to 7 for these sets of spheres. This value of K^2 was then used in Equations (*31*) and (*32*) for the computation of the lines shown in Figures 9 and 10. It is seen that the experimental data fall very well on these calculated lines. This establishes the applicability of the same pore-shape factor for both single-phase and two-phase extractions. It has also been previously shown (*14*) for the case of single-phase extractions, that the same pore-shape factor held for experimental variation in the nature of the salt, its concentration, inside and outside, the temperature level and the solution ratio. These results on two-phase systems extend the applicability of the pore-shape factor.

Some capillary and sphere extraction data were also obtained for the case where these were filled with a water saturated phenol phase (71.6% phenol). The capillary data obtained are included in Figure 8. A small approximate correction of 0.035 cm. was subtracted from the extraction distance in order to correct the data for a concave upward meniscus which appeared in the capillary. Carefully taken data for several runs gave the results shown in Figure 12. It appears that in some two-phase liquid systems other factors than those considered here, such as capillarity, may need further investigation. Care must also be exercised when considering systems where the differential diffusivities vary greatly with gradient or concentration or where, for example, exceedingly fine capillaries are present in the solid.

The equations developed here and previously (*14*) for single-phase and for two-phase systems now permit the calculation of extraction performance for capillaries, uniformly porous slabs and uniformly porous spheres. One need only determine experimentally a single quantity, K^2, to characterize the effect of a uniformly porous solid on diffusion. For example, knowing the length, concentration, solution ratio and diffusivity for the system of interest, one can use the equations to determine the time and per cent extraction curve.

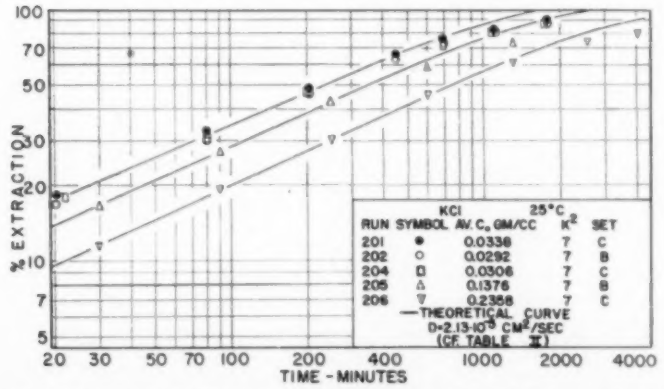


Fig. 10. Extraction of solid KCl from porous alumina spheres using dilute KCl solutions as solvent.

Notation

A = area, sq.cm.

B = over-all rate of solute leaving the interface, g./(sq.cm.) (sec.)

C = concentration of solution, g./cc.

C_s = concentration at interface, g./cc.

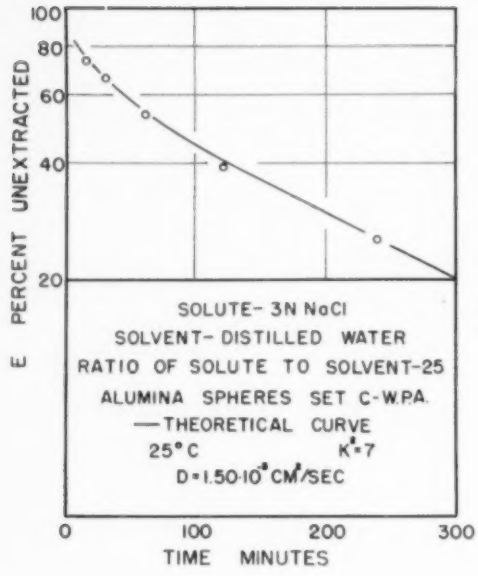


Fig. 11. Determination of the pore shape factor for sets used in this investigation by use of single-phase system.

t = time, sec.

v^{ϕ} = velocity of solvent at any point in diffusion path relative to capillary wall, cm./sec.

w = quantity of solute, g.

W = weight of solid solute, g.

x = distance, cm.

x_s = distance from capillary entrance to interface, cm.

α = fractional volume of solid solute in solute bed

β = distance, cm.

ρ_a = apparent density of solute bed, g./cc.

ρ_s = density of saturated solution, g./cc.

ρ_t = density of solid solute, g./cc.

ψ^* = inverse error function

Acknowledgment

The assistance in this project of the Graduate School and of the Engineering Experiment Station of the University of Minnesota is gratefully acknowledged.

ΔC = concentration driving force between interface and capillary entrance, g./cc.

$\left(\frac{\partial C}{\partial x}\right)_i$ = concentration gradient at interface in straight capillary, g./cc./cm.

$\left(\frac{\partial C}{\partial r}\right)_i$ = concentration gradient at interface in sphere, g./cc./cm.

D = diffusivity constant, sq.cm./sec.

E = per cent of extractable material remaining unextracted

K^2 = pore-shape factor of porous media

M = concentration constant in two-phase capillary equation

p = porosity of porous media, ratio of void volume to total volume

P = rate of solute leaving interface by diffusion, g./(sq.cm.) (sec.)

Q = rate of solute carried to interface by solvent flow, g./(sq. cm.) (sec.)

r = radius at any point in a sphere, cm.

R = radius of a sphere, cm.

s = point of inflection constant of two-phase capillary equation

S = distance from center of sphere to interface, radius of unextracted portion of sphere, cm.

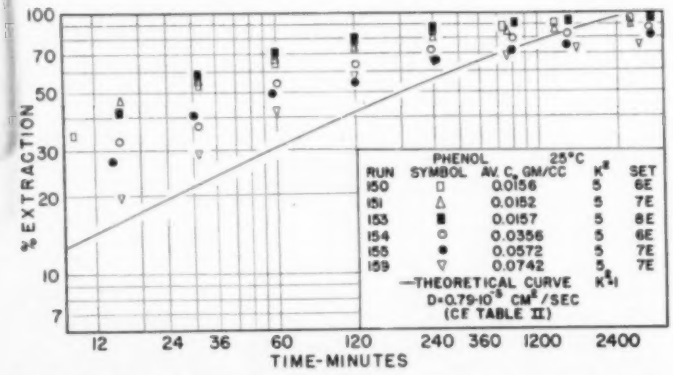


Fig. 12. Extraction of saturated phenol solution from porous alumina spheres using dilute phenol solutions as solvent.

Literature Cited

1. Barrer, R. M., "Diffusion in and Through Solids," The Macmillan Company, New York (1941).
2. Burrage, L. J., *J. Phys. Chem.*, **36**, 2166 (1932).
3. Eversole, W. G., Kindsvater, H. M., and Peterson, J. D., *J. Phys. Chem.*, **46**, 370 (1942).
4. Eyring, H., Irish, E. M., and Stearn, A. E., *J. Phys. Chem.*, **44**, 981 (1940).
5. Dalla Valle, J. M., "Micromeretics," Pitman Publishing Corp., New York (1948).
6. Hermans, J. J., *J. Colloid Sci.*, **2**, 387 (1947).
7. Klotz, I. M., and Miller, D. K., *J. Am. Chem. Soc.*, **69**, 2557 (1947).
8. McBain, J. W., and Dawson, C. R., *Proc. Roy. Soc. (London)*, **A148**, 32 (1935).
9. McBain, J. W., and Liu, T. H., *J. Am. Chem. Soc.*, **53**, 59 (1931).
10. Mitchell, G. E., Ph.D. Thesis, University of Minnesota (1940).
11. Newton, J., "An Introduction to Metallurgy," John Wiley & Sons, New York (1938).
12. Oholm, L. W., *Z. physik. Chem.*, **70**, 378 (1910).
13. Oholm, L. W., *Finska Kemistsamfundets Medd.*, **49**, 14-17 (1940).
14. Piret, E. L., Ebel, R. A., Kiang, C. T., and Armstrong, W. P., *Chem. Eng. Progress*, **47**, No. 7, 405 (1951).
15. Stoughton, B., and Butts, A., "Engineering Metallurgy," 3rd Ed., McGraw-Hill Book Co., New York, p. 108 (1938).
16. Sullivan, J. D., *Trans. Am. Inst. Min. Eng.*, **106**, 515 (1933).

(*Presented at Boston Meeting, Swampscott, Mass.*)

HEAT TRANSFER

Between a Vertical Tube and a Fluidized Air-Solid Mixture

WILLARD M. DOW* and MAX JAKOB

Illinois Institute of Technology, Chicago, Illinois

The transfer of heat from a vertical tube wall to fluidized beds of small solid particles was investigated experimentally in 2-in. and 3-in. diameter tubes. The fluidized mixture consisted of particles of three different solid materials, Aerocat, pitch coke and iron, suspended in an upward flowing stream of air entering at average velocities of ¼ to 1 ft./sec. Heat-transfer coefficients as great as 174 B.t.u./(hr.)(sq.ft.)(°F.) were observed. A heat-transfer mechanism was conceived which involves a narrow thermal layer next to the tube wall, a limited thermal mixing region at the bottom of the fluidized bed and a large thermal equilibrium region throughout the remainder of the bed. This concept was used as a guide for a dimensionless correlation of the experimental data for mechanically smooth, dense-phase fluidization. It involves the following variables: mean heat-transfer coefficient, tube diameter, particle diameter, fluidized bed height, air velocity, physical properties of the air, and the specific heat and density of the solid particles. Conditions of slugging and channeling have a marked influence on the rate of heat transfer.

A COLUMN of finely divided solid particles, which are individually suspended and set in continuous motion by a rising stream of gas, has been termed a fluidized bed. The gas with the suspended solid particles exhibits characteristics which are similar to those normally associated with liquids, such as, mobility, fluidity, hydrostatic pressure, and an upper free surface. Qualitative descriptions of this behavior have been given by numerous writers (*13, 14, 15, 21, 22, 24, 25, 26*).

Though the properties of a fluidized bed were appreciated 50 years ago, only recently have the fluidizing processes received the interest of industry. The inherent advantages of fluidized systems, such as uniform temperature throughout the bed and large surface area available for heat transfer and chemical reactions, have made the fluidizing technique applicable in many commercial operations. The fluid catalytic cracking process was introduced to the petroleum industry during World War II. Other processes now utilizing fluidization in industry are regeneration of catalyst, solid-gas reactions, gasification of coal, Fischer-Tropsch reactions, and preparation of lime.

Most recent articles on fluidization are descriptive acclaims of new processes. Investigations of fluidization fundamentals have been primarily concerned with the study of fluid-flow characteristics (*15-17, 22, 25, 26*). Since the completion of the present investigation,† four experimental studies of heat transfer to fluidized beds have been reported in the literature. Three of the investigations (*11, 19, 20*) were exploratory in nature and were not conducted to obtain a general correlation of the factors controlling the heat-transfer process. Leva, Weintraub, and Grummer (*18*), however, made an attempt to isolate the important variables and correlate them by means of an empirical equation.

The present investigation deals with the steady-state heat transfer from a vertical tube wall to a mixture of small solid particles and air. Ostensibly, this is a complex case, where heat is transferred from the tube wall to the air, as well as between the solid particles and the air. The experiments were undertaken to determine the main factors which affect the heat transfer and to gain an insight to its mechanism, so that a sound correlation of the experimental data could be made.

Various types of behavior of fluidized gas-solid mixtures have been qualitatively established (*22*). At relatively low gas velocities the appearance of a fluidized bed is somewhat like that of a boiling liquid with a definite solid-gas interface at the top of the bed. This condition is referred to as "dense-phase" fluidization. At relatively high gas velocities the entrainment of solid particles by the gas leaving the bed becomes so great that the definite interface disappears and the fluidized region is limited only by the confining vessel. This condition is referred to as "lean-phase" fluidization. Three types of behavior with gas-solid mixtures in dense-phase fluidization have been established (*22*). Under certain conditions, usually for small par-

* Present address: United Gas Corp., Shreveport, La.

Complete experimental data are on file (Document 3314) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Data obtainable by remitting $1.00 for a microfilm and $4.35 for photoprints.

† The experimental investigation which was conducted at the Institute of Gas Technology, Chicago, was completed in June, 1948, and used for the doctoral dissertation of W. M. Dow.

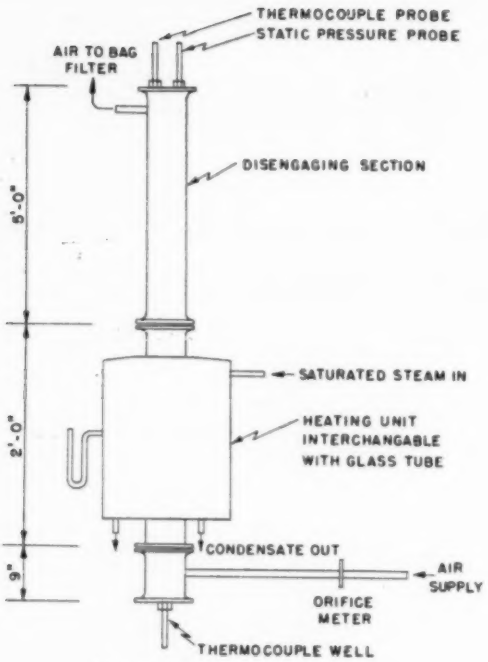


Fig. 1. General arrangement of apparatus.

ticle sizes, the gas tends to channel through the bed without causing a mobile suspension of the solid particles. Under other conditions, such as large bed heights, large particle sizes and high gas flow rates, slugging takes place which is analogous to bumping often observed when liquids boil. The third type of behavior is described as mechanically smooth fluidization. In this case the particles move along twisting, ever-changing paths which, in vessels of 2 to 4 in. in diameter, are primarily upward in the center part of the tube and downward along the tube wall. Occasionally gas bubbles appear in the bed but there is no rough bumping. It is for this case that the pressure drop attending the upward passage of the gas through the bed is nearly equal to the suspension head opposing the flow (*22, 25*).

The present investigation was limited to air-solid systems undergoing mechanically smooth, dense-phase fluidization.

Description of Procedure and Apparatus. Because the total heat input into a fluidized bed in a laboratory-size column is small, it was necessary to design a heating device which would permit only small heat losses. For this reason a double steam-chamber design was selected. By maintaining the outer steam chamber at the same pressure as the inner chamber, radial heat losses were prevented. Axial heat losses were reduced by making the tube wall thin at both ends of the fluidizing section. The axial gradient of the wall temperature was measured in order to determine these losses. The heating section was preceded by a short entrance section and followed by a disengaging section. Air, which was metered by an orifice, entered the bottom of the entrance section, flowed upward through the fluidized bed in the heating section and out the top of the disengaging section to a bag filter. The lower level of the column of solids was fixed by a porous coke disk. Steam was generated in a small gas-fired boiler and introduced at the top of the outer steam chamber. Condensate was collected from the bottom of both steam chambers. The total heat input was calculated from the amount of condensate collected from the inner chamber by means of Nusselt's equation for the condensation of saturated steam. Static pressure and temperature measurements were taken within the fluidized bed by means of movable probes.

Figure 1 shows the general arrangement of the apparatus, while Figure 2 gives details of the heater, though not in scale. Two different size units were used, the inner tube diameters being 2.06 and 3.07 in., the total lengths 23.00 and 26.50 in., respectively. The outer diameter of the outer steam chamber was 6.50 in. in both cases.

With the heaters replaced by glass tubes of appropriate diameters, preliminary experiments could be conducted for visual observation of the limits of smooth fluidization and the conditions under which slugging and channeling occurred.

Heat-transfer runs were made when the tubes were empty, as well as when solids were present and a state of fluidization existed. Three different types of solids were investigated. Experimental runs were made with various particle sizes each under various conditions of air rate and height of the fluidized bed. Static-pressure readings taken at various distances from the porous coke disk indicated this height in a reliable manner. The solid particles used in an experiment were weighed and their average size was determined before and after the runs. Entrainment of the solids by air occurred only with the lightest material used.

Solid Materials. Various size distributions of Aerocat, pitch coke and powdered

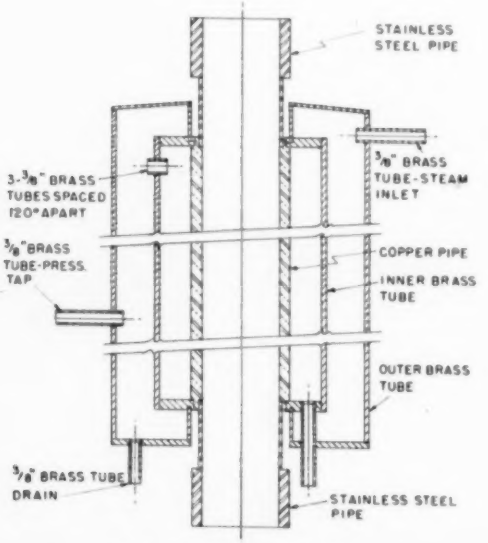


Fig. 2. Cross sectional view of heating unit.

iron were investigated. Aerocat is a synthetic fluid-cracking catalyst manufactured by the American Cyanamid Co. It is a microspheroidal silica-alumina-type catalyst. Comercial grade MS-A Aerocat was separated into four different size distributions for the heat-transfer experiments.

The second material was ground Koppers pitch coke, produced at a coking temperature of about 2650° F. Three rather narrow size distributions of the coke were used in the heat-transfer tests.

Only one size group of the powdered iron was investigated. This powder was obtained by the reduction of iron oxide ore.

Table 1 gives the characteristics and physical data of the solids. The apparent particle densities were determined by means of a mercury pyknometer, while the results from a water pyknometer were taken as an indication of the true solid densities. The size distribution was determined by sieving with U. S. Sieve Series according to A.S.T.M. standards. The arithmetic average was used as the particle diameter. The specific heats were determined calorimetrically at a mean temperature of 200° F. Figures 3, 4 and 5 are photomicrographs of some of the solid particles.

TABLE 1.—PROPERTIES OF SOLID MATERIALS

Solid Material	Particle Size Range (μ)	Average Particle Size (μ)	Apparent Particle Density (lb. mass/cu. ft.)	True Solid Density (lb. mass/cu. ft.)	Specific Heat B.t.u./(lb. mass)(°F.)
C Aerocat	37-297	120	52	124	0.276
D Aerocat	37-210	88	53	124	0.276
E Aerocat	105-350	170	52	124	0.276
F Aerocat	53-149	92	52	124	0.276
G Coke	105-250	161	121	121	0.223
H Coke	74-177	108	121	121	0.223
J Coke	44-125	77	121	121	0.223
K Iron powder	37-149	69	328	466	0.117

Temperature Measurements. Various temperature measurements were taken by means of thermocouples. All thermocouples were made from 30-gage, Leeds and Northrup copper-constantan, duplex wire with glass insulation. A cold junction of melting ice was used as a reference junction for all calibration and subsequent measurements. The thermocouples were calibrated by means of a hypsometer. An average accuracy within 0.1° F. was obtained.

Movable thermocouple probes were used for making temperature measurements within the fluidized bed at various distances from the porous coke disk and the tube wall. Details of these probes and their locations are given in Figure 6. Determination of air temperatures by means of a thermocouple probe is a delicate measurement when the linear velocity of the air is small. However, one can predict the measurement error by mathematical considerations. If the thermocouple probe is considered as a finite solid rod, of length L_1, whose temperature is a function of length only, protruding from a constant temperature sink into a constant temperature fluid medium, then the following expression can be derived for the ratio of temperature differences at the ends of the probe (*2*):

$$\frac{\theta_1}{\theta_0} = \frac{1}{\cosh(mL_1) + B\sinh(mL_1)}$$

where,

θ_1 = temperature excess of free end above environment
θ_0 = temperature excess of sink above environment
$m = \sqrt{hC/kA}$
A = cross-sectional area of probe
$B = h/mk$
C = outer circumference of cross section of probe

Table 2 gives the results of this calculation for possible thermocouple probes when subjected to conditions approximating the most drastic anticipated in the actual heat-transfer experiments $L_1 = 0.50$ ft. and $h = 1$ B.t.u./(hr.)(sq.ft.)(° F.). Since in the actual experiments θ_0 was as great as 10° F., it is obvious that the brass and low carbon steel tubes would have been susceptible to large errors. Therefore, 5/32-in. stainless steel tubes were used for the thermocouple probes. The probes were also chromium-plated and polished to reduce radiation and the adherence of solid particles.

The mean temperature of the outer surface of the fluidization tube was calculated by Nusselt's equation for film-type condensation on a vertical tube (*8*). It was found to be smaller than the saturated steam temperature by some hundredths of a degree Fahrenheit only. The temperature drop through the copper pipe was also negligible. Therefore, the mean temperature of the inner surface of the fluidization tube was taken as equal to the saturated-steam temperature in the inner steam chamber.

In order to evaluate heat losses, thermocouples were placed on each of the thin end sections of the fluidization tube. Those close to the ends of the main heating section were inserted in wells. The locations of these thermocouples are shown in Figure 7. The lower end of the disengaging section was wrapped with a heating coil to reduce heat losses. The temperature of the entering air was measured just below the porous coke disk by a thermocouple inserted in a well which was supported by the flange at the bottom of the entrance section.

Heat Input Measurements. The heat liberated by condensation and calculated from the amount of condensate withdrawn from the inner steam chamber, minus the heat losses from both ends of the copper pipe containing the fluidized bed was taken as the heat input. Condensate was withdrawn from the inner chamber through the middle horizontal leg of a glass T-tube. A constant water level was maintained in the upper vertical leg of that tube by regulating the flow of condensate through a stopcock in the lower vertical leg.

Thermocouple readings established the temperature gradient at each end of the copper pipe, and permitted the calculation of the heat losses (*3*). These varied from 8 to 50% but were generally within 15 to 20% of the heat input.

Preliminary experiments with air flowing through the empty copper tube provided a means for checking the heat input measurements. Excellent heat balances were obtained when the value calculated as indicated above was compared with the heat gained by the air.

Pressure-Drop Measurements. Static-pressure readings were taken within the fluidized bed with a movable probe which was supported in the same manner as the thermocouple probe shown in Figure 6. Adopting a procedure, used in condensation experiments (*9, 10*), a small amount of air was passed through the static-pressure probe and out into the fluidized bed to prevent the small solid particles from plugging the 5/32-in. tube. This quantity of air was passed through a liquid bubbler and

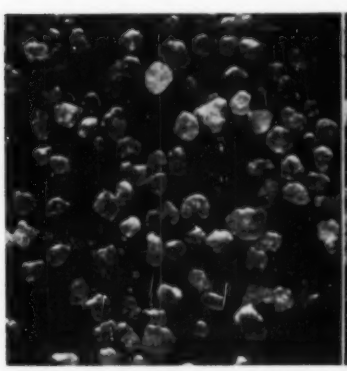


Fig. 3. Photomicrograph of Aerocat solid E

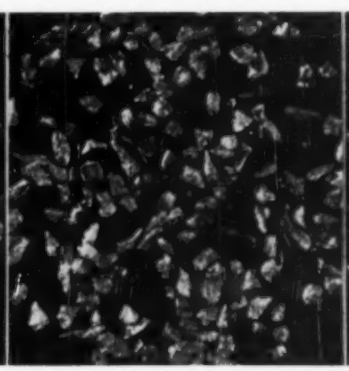


Fig. 4. Photomicrograph of coke solid H

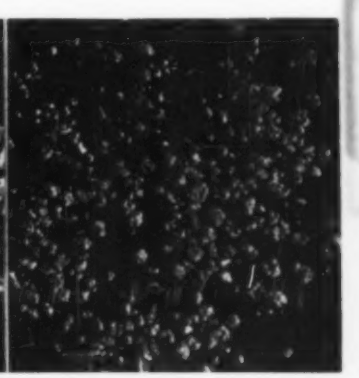


Fig. 5. Photomicrograph of iron solid K

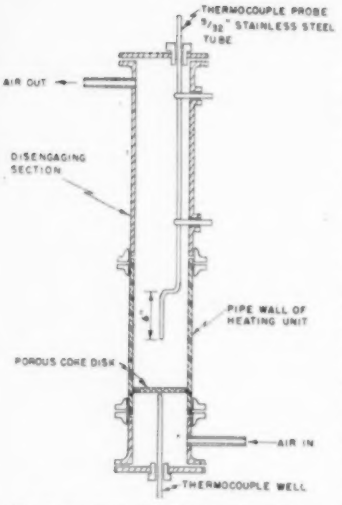


Fig. 6. Arrangement of thermocouple probes.

was controlled by a needle valve. The pressure drop caused by the air flow was kept negligibly small compared to the static pressure within the bed.

Static-pressure readings were taken at intervals of one in. or less throughout the entire height of the fluidized bed in all experimental runs. A constant pressure gradient throughout the height of the fluidized bed was observed in smooth fluidization, while slugging was accompanied by a decrease of the pressure gradient with increasing height, as well as pressure fluctuations.

The Mechanism of Heat Transfer in Fluidization

Qualitative observations of fluidized air-solid mixtures in 2-in. and 3-in.

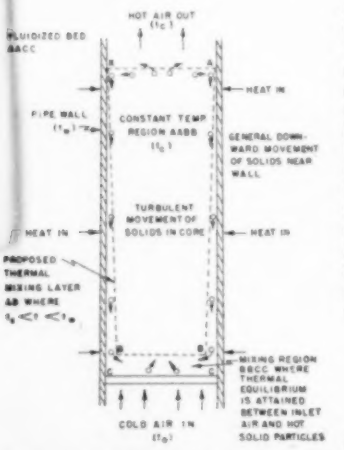

HOT AIR OUT
HEAT IN
CONSTANT TEMP REGION AABB
GENERAL DOWNWARD MOVEMENT OF SOLIDS NEAR WALL
TURBULENT MOVEMENT OF SOLIDS IN CORE
HEAT IN
HEAT IN
PROPOSED THERMAL MIXING LAYER AB WHERE
MIXING REGION BCCC WHERE THERMAL EQUILIBRIUM IS ATTAINED BETWEEN INLET AIR AND HOT SOLID PARTICLES
COLD AIR IN

Fig. 8. Idealized heat transfer mechanism and particle movement.

diam. glass tubes revealed a movement of the small solid particles as indicated in Figure 8. Their downward movement at the wall was very definite, although irregular and even interrupted for short periods of time, giving a slightly surging movement to the flow. In rough quantitative observations particles were followed and timed for distances of three to six in. during their fall. In general, the particle velocity was about one or two in./sec. and appeared to be proportional to the main air flow. No change of particle velocity could be detected with varying fluidized bed height. The particles did not behave like free-falling bodies in a gas stream, but had a forced, irregular motion downward. There was no general horizontal movement of the particles near the wall except at the top of the fluidized bed and in a rather turbulent mixing region at the bottom of the fluidized bed.

Temperature explorations conducted during the heat transfer experiments showed that the entire fluidized bed was at a constant temperature except for a very small region at the bottom and a narrow layer near the tube wall. The overall heat transfer between the tube wall and the fluidized mass was exceptionally great. It is untenable to account for these two remarkable physical features with an explanation involving rapid mixing and frequent contacts of solid particles with the tube wall. The contact surface and time would be too small to allow an appreciable amount of heat transfer by conduction. The only conceivable heat transfer mechanism seems to consist of radial transfer of heat from the tube wall through an air film of a few thousandths of an inch thickness with subsequent transfer to air flowing outside this film and to the solid particles moving downward along the wall. The heat transferred radially from the tube wall is picked up by the downward moving solid particles within a very short distance from the wall and carried to the bottom of the fluidized bed, where thermal equilibrium between them and the incoming cold air is attained almost instantaneously. Except in these layers along the wall, whose maximum thickness in the present experiments was about ¼ in., and in the limited mixing region at the bottom of the bed, thermal equilibrium between the particles and the gas very nearly exists throughout the fluidized bed.

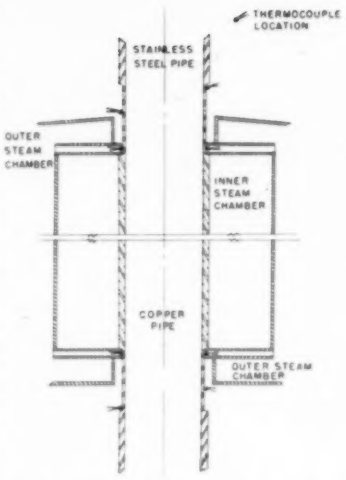


Fig. 7. Location of thermocouples for heat loss measurements.

A few considerations will show that such a mechanism is compatible with heat transfer fundamentals. However, there is one salient point in the proposed mechanism which can be explained only by reference to the momentum and heat transfer analogy (*5*). Possibility of appreciable heat transfer from the tube wall to the solid particles by direct conduction has been precluded and thermal conductivity of the solid-air mixture is approximately the same as that of air alone. It is proposed that heat is transferred through an air film to a fluid with practically the same thermal properties as air at a rate a hundred-fold greater than that which would exist for air alone moving through the tube. The difficulty is to explain how an air film as thin as would only occur at very high air velocities may be formed. Supposedly, the bombardment with small solid particles prevents the formation of a laminar boundary layer and leaves only a sort of sublayer which virtually never can be entirely removed and a thicker turbulent layer, in both of which the particles receive heat energy from the air. In terms of the momentum theory of heat convection this would mean that the mechanical and thermal eddy diffusivities are unusually large and control the heat transfer.

The heat transfer between air and solid particles requires only a slight

TABLE 2.—TEMPERATURE INDICATIONS OF VARIOUS THERMOCOUPLE PROBES

Thermocouple Probe	Diameter in.	Wall Thickness in.	h B.t.u./(hr.)(ft.)(°F.)	$\frac{\theta_1}{\theta_0}$
Brass tube	0.187	0.032	60	0.600
Low carbon steel tube	0.156	0.032	25	0.224
Stainless steel tube	0.156	0.0164	10	0.022
Stainless steel tube	0.125	0.0164	10	0.020

temperature difference. The most conservative case would be that of a spherical particle of diameter D_p in an infinitely extended space of perfectly still air. According to Ruedenberg (*23*) the thermal surface resistance would be $R = 1/2\pi D_p k$, leading to $h = 2k/D_p$. For particles of 100μ in diam., which was the order of magnitude of the particle diameters studied experimentally, heat transfer coefficients in still air of approximately 100 B.t.u./(hr.)(sq.ft.)(°F.) should be expected. Considering that there were about 20 sq. ft. of particle surface area per inch of fluidized bed height in the present experiments, one may readily deduce that thermal equilibrium may have been established within a fraction of an inch above the bottom of the bed.

From the theory of conduction in a sphere suddenly brought into an environment at a different temperature (*2, 4*) it can further be seen that temperature gradients within the small particles were negligible throughout the process. Therefore, the heat transfer coefficient between the tube wall and the fluidized mass should be virtually independent of the thermal conductivities of the solids.

Under these assumptions the following heat balance for the unsteady heat transfer to spherical particles at temperature, t_a, suddenly introduced into air at constant temperature, t_a, is obtained:

$$dQ = h_p A_p (t_a - t) d\tau = V_p \rho_s c_s dt$$

Integrating,

$$\ln\left(\frac{t_a - t_a}{t_a - t}\right) = \left(\frac{h_p A_p \tau}{V_p \rho_s c_s}\right)$$

and with $h_p = 2k_a/D_p$,

$$(t_a - t) = \frac{(t_a - t_a)}{e^{\left(\frac{12 k_a \tau}{D_p \rho_s c_s}\right)}}$$

Application of this equation to the present experiments showed that the particles falling along the wall assumed the temperature of the surrounding air within 0.1° F. in about 0.1 sec.

Finally it will be verified that the proposed mechanism of heat transfer is compatible with the observations of particle velocities of 1 or 2 in./sec. in a thermal layer along the wall of about ¼ in. thickness. When N_p particles, with a temperature excess θ above the bed temperature, enter the mixing region at the bottom per unit of time—the average particle temperature being arbitrarily taken as the mean between wall temperature and bed temperature—then the rate of heat energy carried down is

$$q_w = N_p \rho_s c_s V_p \theta$$

Since the number of particles per unit volume is $(1 - \epsilon)/V_p$,

$$N_p = b\pi D_t u_p (1 - \epsilon)/V_p$$

where b is the thickness of the thermal layer. A combination of these two equations gives

$$b = \frac{q_w}{\pi(1 - \epsilon)\rho_s c_s D_t u_p \theta}$$

Values from representative experimental runs substituted in this last equation yield values of b of the order of magnitude of ¼ in. or less, which is in agreement with the temperature measurements across the bed.

Summarizing, it is assumed that the heat-transfer mechanism consists of two parts as follows:

1. Transfer of heat from the tube wall through a very thin air film to a somewhat thicker air layer and from the air to solid particles moving downward near the wall. This mechanism is similar to the mechanism of nuclear boiling on a heating surface where the heat energy also makes a detour from the surface over the liquid to the vapor bubble (see, for instance, *7*).
2. Transfer of heat in a mixing region at the bottom of the fluidized bed from the heated particles, which have fallen along the wall, to the incoming cold air.

Only with such a mechanism could we explain the observation of heat transfer rates a hundred-fold greater than those which would be predicted for air alone, and the existence of the large constant temperature region in the fluidized bed. This mechanism predicts that the large constant temperature region could be destroyed if the downward flow of the small particles along the wall was disturbed so that some of the heated particles were short-circuited into the main flow before they reached the bottom. This was observed in cases of slugging.

Since it would be difficult to find an analytical form for this mechanism without making some bold assumptions, for instance, concerning the velocity and temperature of the particles falling along the wall, the experimental data were merely correlated according to dimensional-analysis considerations by a power function of dimensionless groups.

Correlation by Dimensional Analysis

If the described heat transfer mechanism is substantially a true representation of the actual mechanism, then it may serve as a guide in selecting the important factors controlling the heat transfer to fluidized beds. Various factors which appeared to be important in such a mechanism were selected and correlated by dimensional analysis.

If one considers that the heat is transferred through an air layer at the wall surface, and then to the falling particles which carry the heat into the mixing region at the bottom of the bed, it seems probable that the important factors are those listed in Table 3. In accordance with the theoretical considerations, the thermal conductivity of the solid particles was omitted. Certain other factors such as shape of the particles and dispersivity of the particles, which may be involved, were also neglected. The acceleration due to gravity was included as this affects the movement of the solid particles.

The correlation of these factors by dimensional analysis resulted in an appropriate grouping of the variables into dimensionless groups, and the experimental data served as a basis for determining the correctness and adequacy of the original assumptions. The dimensional analysis then resulted in the following equation of dimensionless groups:

$$\frac{h_m D_t}{k_g} = \text{const.} \left(\frac{L}{D_t}\right)^a \left(\frac{D_t}{D_p}\right)^b \left(\frac{c_g \mu_g}{k_g}\right)^c \left(\frac{D_p G}{\mu_g}\right)^d \left(\frac{\rho_s c_s}{\rho_g c_g}\right)^e \left(\frac{(1 - \epsilon)(\rho_s - \rho_g) g D_p}{u_0^2 \rho}\right)^f \quad (1)$$

The last group represents the ratio of the force of gravity to the force of resistance on spherical particles in a moving fluid.

TABLE 3.—FACTORS WHICH MAY AFFECT HEAT TRANSFER

Factor	Symbol
Entrance gas velocity (quantity flowing per unit cross-sectional area of empty tube)	u_0
Height of fluidized bed	L
Average particle diameter	D_p
Tube diameter	D_t
Solid particle density	ρ_s
Specific heat of solid	c_s
Density of gas	ρ_g
Specific heat of gas	c_g
Thermal conductivity of gas	k_g
Viscosity of gas	μ_g
Acceleration due to gravity	g
Mean heat transfer coefficient	h_m
Fraction voids	ϵ

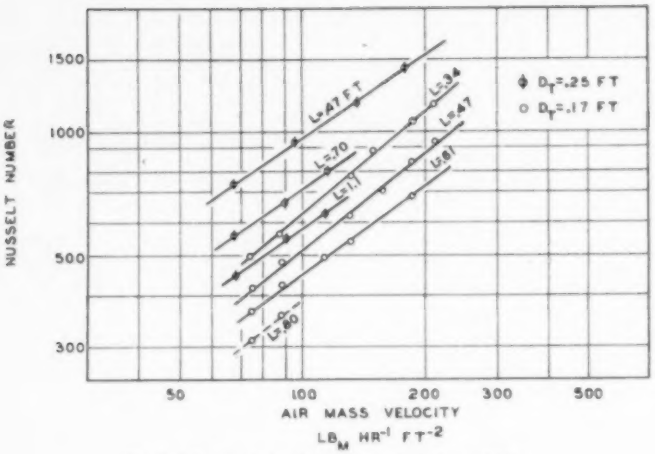


Fig. 9. Influence of air velocity on Nusselt number, solid H.

TABLE 4.—NUMERICAL VALUES OF INVESTIGATED VARIABLES

Item	Symbol	Values or Range of Values
Tube diameter	D_t	2.067 in. & 3.068 in.
Particle diameter	D_p	69, 77, 88, 92, 108, 120, 161, 162, 170 μ
Air mass velocity	G	60 to 305 lb. mass/(hr.)(sq.ft.)
Heat capacity of solids	$\rho_s c_s$	14.45, 26.60 & 38.25 B.t.u./(cu.ft.)(°F.)
Fluidized bed height	L	1.7 to 14.1 in.
Mean heat-transfer coefficient	h_m	20 to 174 B.t.u./(hr.)(sq.ft.)(°F.)
Heat input	q_w	20 to 300 B.t.u./(hr.)
Temperature excess	θ	1.8 to 11.0 °F.
Fraction solids	$1-\epsilon$	0.31 to 0.47

Experimental Results

One hundred and ninety-one experiments were conducted with three kinds of solid particles which were separated into eight narrow ranges of particle size. In addition, 32 experiments were conducted with no solids present in the heating units. These exploratory runs with empty tubes insured the reliability of the experimental measurements and gave values for the mean heat-transfer coefficient of the order of magnitude of 1 B.t.u./(hr.)(sq.ft.)(° F.).

The range of the experiments is shown in Table 4, while summaries of the experimental runs are given in Tables 5 and 6. The experimental data were correlated according to the resulting equation from the dimensional analysis considerations. The Prandtl number was constant for all experimental runs so it was absorbed in the constant coefficient. The Nusselt number proved to be independent of the dimensionless group representing the ratio of the force of gravity to the force of resistance on the solid particles.

For illustration of the correlating procedure some plots, all pertaining to fluidized coke beds, are presented. Figure 9 shows the influence of air mass velocity upon the Nusselt number for coke H. This solid has been chosen for the illustration because its D_p is approximately the average of all sizes used, as may be seen from Table 1. The influence is shown, with the bed height L as a parameter, for the two tube diameters. For any one series of experimental runs all other variables, D_p, $(1-\epsilon)$, $\rho_s c_s$, k_g, μ_g, c_g, ρ_g, remained constant within the limits of experimental inaccuracies. Similar plots were obtained for the other solids. An average of the experimental data for all substances investigated gave

$$N_{Nu} = \frac{h_m D_t}{k_g} \sim G^{0.80}$$

where h_m is defined as

$$h_m = \frac{q_w}{A_w(t_w - t_e)}$$

Figure 10, again for coke H, shows a plot of the Nusselt number vs. the height of the fluidized bed for fixed values of the mass velocity, all other variables remaining constant. An average for all substances gave

$$N_{Nu} = \frac{h_m D_t}{k} \sim L^{-0.65}$$

Figure 11 is a plot of the quantity

$$\left[\frac{N_{Nu}(L/D_t)^{0.65}}{(N_{Re})^{0.80}}\right]$$

vs. D_t/D_p for the three coke fractions G, H, and J for experimental runs conducted with both heating units.

Figures 12, 13 and 14 are plots of the quantity

$$\left[\frac{N_{Nu}(L/D_t)^{0.65}}{(D_t/D_p)^{0.17}}\right]$$

vs. the Reynolds number, $D_t G/\mu_g$, for the three solids. These curves can be represented by the following equations:

Aerocat:

$$\frac{h_m D_t}{k_g} = 2.9\left(\frac{D_t}{L}\right)^{0.65}\left(\frac{D_t}{D_p}\right)^{0.17}\left(\frac{D_t G}{\mu_g}\right)^{0.80} \quad (2)$$

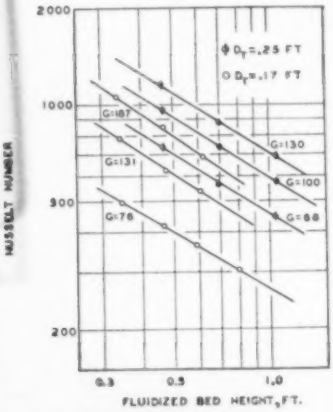


Fig. 10. Influence of bed height on Nusselt number, solid H.

TABLE 5.—SUMMARY OF EXPERIMENTAL RUNS
(Small Heating Unit)

Solid	Average Particle Diameter (μ)	u_w (ft./sec.)	h_m B.t.u./(hr.)(sq.ft.)(°F.)	Height of Fluid Bed (ft.)
None		0.25 to 2.00	0.7 to 1.1	1.33
None	Coke disk present	0.25 to 2.00	0.8 to 1.7	1.33
E	170	0.25 to 1.00	16.0 to 125	0.25 to 1.00
C	120	0.25 to 0.67	19.0 to 102	0.14 to 1.20
D	88	0.25 to 0.40	19.0 to 60	0.30 to 1.20
F	92	0.25 to 0.40	20.0 to 42	0.37 to 1.20
G	161	0.25 to 0.88	44.0 to 103	0.38 to 0.50
H	108	0.25 to 0.88	32.0 to 121	0.34 to 0.80
J	77	0.25 to 0.50	40.0 to 92.0	0.33 to 1.00

Coke:

$$\frac{h_m D_t}{k_g} = 3.7\left(\frac{D_t}{L}\right)^{0.65}\left(\frac{D_t}{D_p}\right)^{0.17}\left(\frac{D_t G}{\mu_g}\right)^{0.78} \quad (3)$$

Iron:

$$\frac{h_m D_t}{k_g} = 3.4\left(\frac{D_t}{L}\right)^{0.65}\left(\frac{D_t}{D_p}\right)^{0.17}\left(\frac{D_t G}{\mu_g}\right)^{0.81} \quad (4)$$

The data for the three solids may be brought together by considering the influence of the heat capacity ratio, $\rho_s c_s/\rho_g c_g$ (Fig. 15). Figure 16 represents the final correlation of all the experimental data. The straight line shown can be represented by the equation:

$$\frac{h_m D_t}{k_g} = 0.50\left(\frac{D_t}{L}\right)^{0.65}\left(\frac{D_t}{D_p}\right)^{0.17}\left(\frac{\rho_s c_s}{\rho_g c_g}\right)^{0.25}\left(\frac{D_t G}{\mu_g}\right)^{0.80} \quad (5)$$

Experimental runs which obviously were operating under conditions of slugging or channeling were not included in the final correlation. The heat transfer coefficients for these runs were always less than those which would be predicted by the final corrlation. Figure 17 shows the results of slugging on a series of experimental runs conducted with the ground coke particles.

Figure 18 gives some typical results of the static pressure readings taken within the fluidized bed. It also shows the effect of slugging. Smooth fluidization was accompanied by a constant pressure gradient throughout the extent of the fluidized bed, and the total height showed no definite tendency to increase with increasing rate of air flow as evidenced by the straight lines and constant break-points of the lines representing smooth fluidization in Figure 18. Under slugging conditions, however, the pressure gradient in the main flow direction decreased and the total height of the fluidized bed increased with the rate of air flow as shown by curves 3A, 3B, and 3C in Figure 18. The values of the parameters of the curves shown in Figure 18 are given in Table 7.

Critical Analysis of the Results

Undoubtedly, there are factors affecting the heat transfer which have not been investigated, one being the particle shape. The coke particles were much more angular than the other solid particles, yet the experimental data indicated no great influence of particle shape on the heat transfer. Other factors may be the dispersivity of the solid particles, and any forces between the particles, such as electrostatic forces.

Because of the low particle density of the Aerocat solid, it was difficult to make experimental runs on the smaller particle sizes, solids C, D and F. The greatest tendency for solid carry-over out of the tube was encountered with these solids. Consequently, low air rates had to be used which caused some scattering of the data. This difficulty might be obviated by conducting experiments under higher pressure conditions.

The present correlation is for a specified condition—smooth, dense-phase fluidization with no channeling or slugging, both of which would reduce the heat transfer coefficient.

The overall inaccuracy of the experimental work is considered to be about 10%. The deviation of the experimental data from the final correlation in Figure 16 is well within these limits, and the average deviation is considerably smaller.

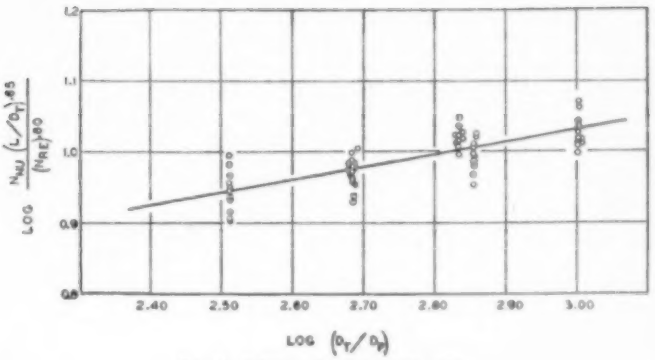


Fig. 11. Influence of diameter ratio, coke.

TABLE 6.—SUMMARY OF EXPERIMENTAL RUNS
(Large Heating Unit)

Solid	Average Particle Diameter (in.)	w_m (ft./sec.)	h_m B.t.u./(hr.)(sq.ft.)(°F.)	Height of Fluid Bed (ft.)
None	Coke disk present	0.25 to 1.00	0.90 to 1.30	1.33
E	170	0.25 to 1.00	20.0 to 63.0	0.34 to 0.75
G	161	0.25 to 1.00	40.0 to 105	0.40 to 0.82
H	108	0.25 to 0.67	30.0 to 100	0.45 to 1.10
J	77	0.25 to 0.67	34.0 to 92.0	0.55 to 1.10
K	69	0.25 to 0.67	64.0 to 174	0.35 to 0.43

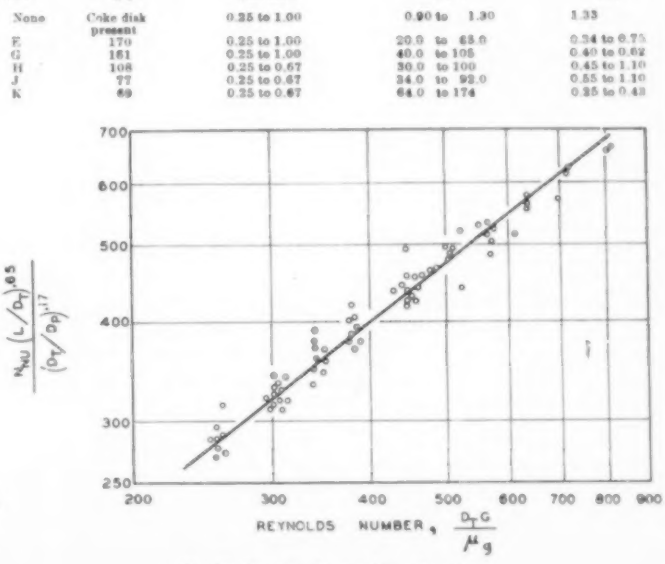


Fig. 12. Heat transfer correlation for coke.

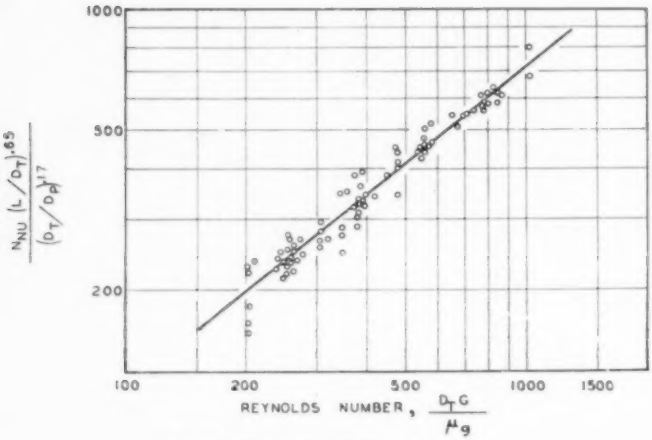


Fig. 13. Heat transfer correlation for Aerocat.

It would be possible to rearrange the final equation so that the Reynolds number and Nusselt number, either one or both of them, would have D_p or even L as the characteristic length. The physical significance of such variations is not clear. A qualitative explanation of the influence of $(\rho_s c_s/\rho_g c_g)$ in the empirical Equation (5) is not difficult. If a mechanism exists by which the solid particles act as powerful carriers of heat energy, then this carrying power will be greater if the specific heat per unit volume is greater. The most startling item is the relationship between Nusselt number and Reynolds number according to Equation (5). The relationship $N_{Nu} = C(N_{Re})^{0.80}$ for tubes generally occurs only at $N_{Re} > 2000$, compared to $N_{Re} = 200$ to 1500 of Figure 16, and then with a much smaller constant factor C than in our case. Our interpretation of this part of Equation (5) is that turbulence behavior starts at low Reynolds numbers because of the mentioned disturbance of the surface film by the solid particles, and the high value of C results from the existence of a very thin sublayer only, also due to the same disturbances. Perhaps the mixture of particles and air close to the surface should be considered as a liquid-like fluid which would have a much smaller kinematic viscosity. Then the Reynolds number would be higher and the factor C smaller. However, this concept would change other pertinent properties, in particular, the Prandtl number. It would be of interest to study the apparent physical properties of such a solid-gaseous mixture.

The final correlation as represented by Equation (5) must be considered as nothing more than an empirical representation of the results, which is consistent with the concepts of dimensional homogeneity. It is not entirely indicative of the mechanism of heat transfer. Means and time available made it necessary to restrict the investigation to air and two tube diameters.

TABLE 7.—PARAMETERS OF THE CURVES OF FIG. 16

Curve	Mass of Solid in Bed, lb. mass	Air Mass Velocity, lb.mass/(sq.ft.)(hr.)	Fluid Bed Height, Inches
1A	0.145	75	3.2
1B	0.145	112	3.2
1C	0.145	164	3.2
2A	0.262	112	5.7
2B	0.262	164	5.7
3A	0.436	112	9.2
3B	0.436	163	9.5
3C	0.436	230	9.8

Shown in Fig. 18.

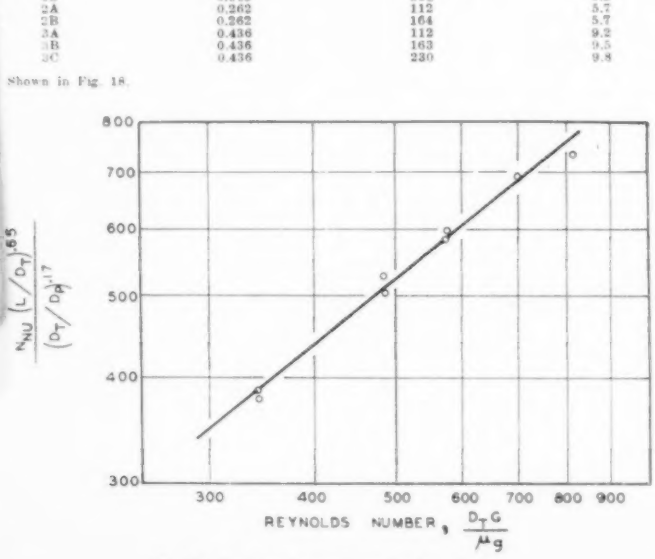


Fig. 14. Heat transfer correlation for iron powder.

Comparison with Previous Work

Parent, Vagol and Steiner (*22*) reported some basic observations on fluidizing processes in laboratory scale equipment. Preliminary experiments on indirect heat transfer did not reveal a change in the heat transfer due to the presence of fluidized solids. They noticed very little variation in temperature throughout the fluidized bed.

Uniform temperature of the fluidized bed has also been noticed by Kalbach (*13, 14*) and by Thomas and Hoekstra (*24*).

Nicholson, Moise and Hardy (*21*) stated that the tremendous heat transfer capacity of the fluidized bed provides truly isothermal conditions for chemical reactions. They also remarked that transfer of heat between the fluidized solids bed and a metal heat transfer surface is at a very high rate. They said that film coefficients of over 300 B.t.u./(hr.)(sq.ft.)(°F.) have been obtained under certain conditions with dense beds of fluidized solids.

According to a feature in a technical journal (*1*) converters for synthetic fuel manufacture utilizing the fluidizing technique are being designed for a heat transfer coefficient of 150 B.t.u./(hr.)(sq.ft.)(°F.).

Johnstone, Pigford and Chapin (*12*) made an extensive theoretical and experimental investigation of heat transfer from a hot furnace wall to clouds of falling particles. They observed coefficients of heat transfer by convection from the furnace wall to the gas which

were several times larger than the value predicted for natural convection alone and depended on the size of the furnace. The coefficient of heat transfer increased with an increase in tube diameter, which is in agreement with the present results.

Since the completion of the present investigation, four experimental studies of heat transfer to fluidized beds have been reported in the literature. Jolley (*11*) performed exploratory experiments designed to show the magnitude of heat transfer to surfaces from fluidized beds of coke particles in air. He concluded that the rate of heat transfer was several times greater than that found with the carrier gas alone or with a static bed of the solid particles.

Levenspiel and Walton (*19*) deter-

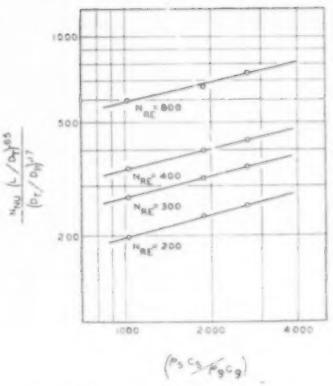


Fig. 15. Influence of heat capacity ratio.

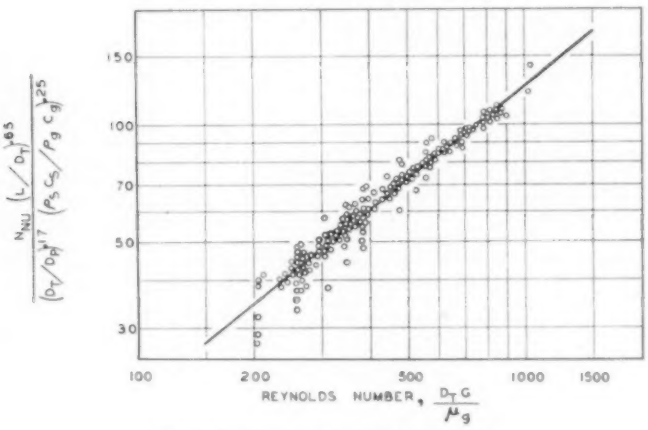


Fig. 16. Final heat transfer correlation, all solids.

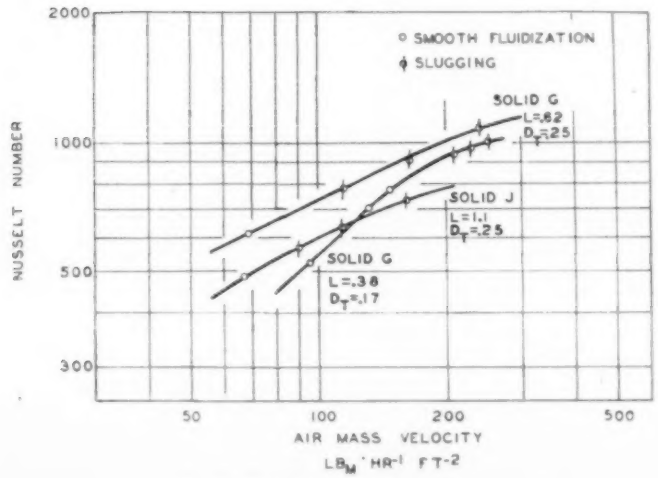


Fig. 17. Effect of slugging on heat transfer.

TABLE 8—SAMPLE DATA OF THE EXPERIMENTAL INVESTIGATION

Solid	Tube Diameter D_T, in.	Air Mass Velocity, lb./(hr.)(sq. ft.)	Surface Temp., °F.	Fluidized Bed Temp., °F.	Height of Fluid Bed, ft.	Static Pressure Gradient, ft. H_2O/ft.	Fraction Solids, $(1-\epsilon)$	q_T Heat Input, B.t.u./hr.	h_m, B.t.u./(hr.)(sq. ft.)(°F.)	Re Number $\frac{D_T v_{max} \rho}{\mu}$	Nu Number $\frac{h_m D_T}{k_g}$
K	0.5	75.6	210.9	206.6	0.271	0.40	0.47	31.0	49.0	266	469
K	0.5	164	210.8	204.3	0.271	0.40	0.48	91.4	93.5	576	913
K	0.5	232.3	210.8	202.9	0.271	0.40	0.46	130.1	124.4	795	1120
K	0.5	251	210.7	202.5	0.271	0.39	0.46	145	127.9	855	1234
K	0.5	275	210.5	204.6	0.604	0.38	0.45	145	87.9	850	709
K	0.5	384	210.2	204.1	0.333	0.60	0.46	226	56.8	555	487
L	0.5	131	210.2	206.9	0.329	0.60	0.31	58.9	66.6	554	581
L	0.5	67.4	211.2	207.9	0.562	0.60	0.33	26.0	47.8	300	650
L	0.5	110	211.2	207.6	0.331	0.60	0.31	51.6	67.8	490	858
L	0.5	167.1	211.2	207.1	0.562	0.65	0.33	71.6	92.4	585	962
L	0.5	69.3	211.2	206.4	0.271	0.38	0.39	19.5	45.3	298	598
L	0.5	115.3	211.1	205.9	0.263	0.39	0.39	32.5	62.5	411	826
L	0.5	162	211.1	204.8	0.260	0.38	0.39	45.1	74.2	543	1190
L	0.5	63.3	211.0	207.5	0.425	0.60	0.39	28.9	74.0	508	1190
L	0.5	96.5	211.0	207.0	0.425	0.60	0.40	43.1	133	874	2460
L	0.5	139	211.0	206.3	0.415	2.09	0.40	61.8	174	914	3915
K	0.25	84.4	210.9	206.6	0.271	0.40	0.47	31.0	78.2	583	1269
K	0.25	225	210.8	202.9	0.271	0.40	0.46	91.4	88.0	495	1690
K	0.25	303	210.7	202.5	0.271	0.39	0.46	130.1	119	700	
K	0.25	725	210.5	204.6	0.604	0.38	0.45	145			
K	0.25	1015	210.2	204.1	0.333	0.60	0.46	226			
L	0.25	384	210.2	206.9	0.329	0.60	0.31	58.9			
L	0.25	184	211.2	207.9	0.562	0.60	0.33	26.0			
L	0.25	300	211.2	207.6	0.331	0.60	0.31	51.6			
L	0.25	455	211.2	207.1	0.562	0.65	0.33	71.6			
L	0.25	185	211.2	206.4	0.271	0.38	0.39	19.5			
L	0.25	285	211.1	205.9	0.263	0.39	0.39	32.5			
L	0.25	410	211.1	204.8	0.260	0.38	0.39	45.1			
L	0.25	175	211.0	207.5	0.425	0.60	0.40	28.9			
L	0.25	255	211.0	207.0	0.425	0.60	0.40	43.1			
L	0.25	360	211.0	206.3	0.415	2.09	0.40	61.8			

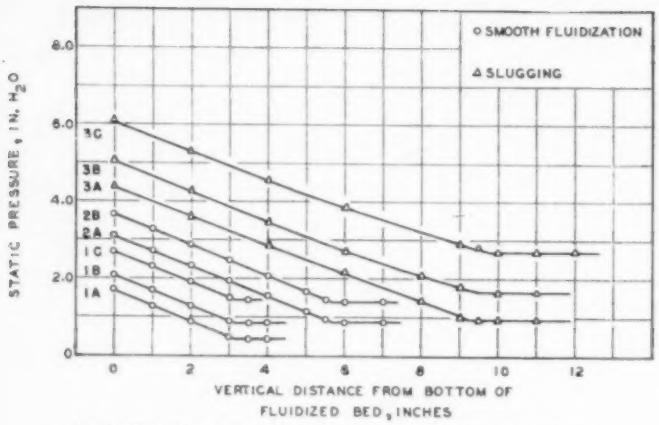


Fig. 18. Typical distribution of static pressures within fluidized bed, solid E.

mined the heat transfer rates from fluidized beds of Utah pulverized coal in air to a 4-in. diam. tube. They found that the heat-transfer coefficient increased with air mass velocity to a maximum value at about 500 lb.mass/(hr.)(sq.ft.) and then remained constant or decreased slightly. In qualitative agreement with our results, they observed that the heat transfer coefficient increased with a decrease in the particle size of the solid. For comparable ranges of particle sizes and air mass velocities the heat transfer coefficients obtained in the present investigation are several times greater than those reported by Levenspiel and Walton. All but two of their particle size distributions were larger than those used in the present study. In fact, we could not obtain smooth fluidization using such large particle sizes with the three solids studied. Qualitatively, their results resemble the data which were obtained under conditions of slugging as shown in Figure 17, and indicate that the heat transfer coefficient may approach a maximum value with increasing mass velocity under slugging conditions.

Mickley and Trilling (*20*) thoroughly investigated the heat-transfer characteristics of fluidized beds of Scotchlite glass beads. They measured the influence of size and concentration of the solid particles, and velocity of the gas on the rate of heat transfer to internally and externally heated fluidized beds. The conditions of the experiments were different from ours in the following regards: local heat transfer coefficients were measured for a section of the total bed height; lean-phase fluidization was used except for the low rates of air flow where slugging was observed; and the rates of air flow were one to ten times greater than the highest rates studied in the present investigation. They observed a similar trend of the heat transfer coefficient with mass rate of flow as reported by Levenspiel and Walton and as shown in Figure 17. In general, their data cannot be compared with the present results. However, heat transfer coefficients found in their and our investigations are of the same order of magnitude and about the same influence of solid concentration on the coefficient was observed. It is felt that their data are, in general, for an entirely different type of fluidization, lean-phase as compared to dense-phase, and included results at low rates of flow which were taken under slugging conditions. It does not seem probable that the same heat transfer mechanism should exist under such conditions as exist under conditions of mechanically smooth, dense-phase fluidization. The fraction solids $(1-\epsilon)$ was not included in the correlation as expressed by Equation (5). The variation of this factor was slight for the three solids investigated and its inclusion did not improve the correlation. In view of the results of Mickley and Trilling it appears that this variable also may be a factor in the heat transfer to beds undergoing mechanically smooth fluidization.

The final correlation of the present experiments as expressed by Equation (5) could be represented as well by a slight modification of this equation which would include the variable ϵ, fraction voids. It may be included in the form of the dimensionless group, $(1-\epsilon)\rho_s c_s/\epsilon\rho_g c_g$, to give a final correlation represented by the equation:

$$\frac{h_m D_t}{k_g} = 0.55\left(\frac{D_t}{L}\right)^{0.65}\left(\frac{D_t}{D_p}\right)^{0.17}\left(\frac{(1-\epsilon)\rho_s c_s}{\epsilon\rho_g c_g}\right)^{0.25}\left(\frac{D_t G}{\mu_g}\right)^{0.80} \qquad (6)$$

Figure 19 shows the experimental data of Mickley and Trilling and of Levenspiel and Walton compared with the present correlation as expressed by Equation (6). The inclusion of the variable ϵ, fraction voids, in our correlation brings the data of Mickley and Trilling into a reasonable agreement with the present correlation, although their experiments were with lean-phase fluidization and involved variations of fraction voids from 0.0158 to 0.439. Their data show an influence of particle diameter which is not indicated by Equation (6). In Figure 19 a different symbol is used for their data of particle diameters greater than 0.007 inches. We could not obtain smooth fluidization with such large particles. Their investigation included experiments with 1 in. and 4 in. diam. tubes. Mickley and Trilling's experimentally measured heat-transfer coefficients are not strictly comparable with our measurements, as they represent an average coefficient measured over a central section about 2 ft. high instead of over the entire height of the fluidized bed. In recalculating their data we assumed that the height of the fluidized bed was the same for all runs in each of the two different diam. tubes, 60 in. for the 4 in. diam. tube and 40 in. for the 1 in. diam. tube. Although they did not report the value of the fluidized bed height, it is likely that there was some variation in it from run to run.

The data of Levenspiel and Walton are similar to those of Mickley and Trilling in that their measured heat-transfer coefficients are local coefficients at about the mid-point of the fluidized bed. In recalculating their data it was assumed that the height of the fluidized bed was 10 in. for all runs.

Leva, Weintraub and Grummer (*18*) measured the heat transfer to fluidized beds of small particles of sand and iron catalyst in 2 and 4-in. diam. tubes. They concluded that the fluidized bed height, the voidage in the bed, the density of the solid particles, the vessel diameter and slugging had no effect on the heat transfer coefficient between the vessel wall and the fluidized bed, whereas channeling had a very pronounced effect. These authors correlated their data as follows:

$$h_m = 0.64\left(\frac{k_g}{\mu_g}\right)GEq$$

$$h_m = 0.86\, c_g GEq$$

and $$h_m = 0.35\, c_g (G)^{1.15}$$

where Eq represents the efficiency of fluidization, a concept they introduced

during earlier studies (*16, 17*). The second equation is merely a modification of the first with an average numerical value of the Prandtl number for all gases. These equations represent the experimental data with an average deviation of about ±25%, the maximum scatter of the experimental data from the correlations being about ±40%. The third equation is more convenient in usage since it does not involve the factor E_ϕ which requires considerable information concerning the system. These equations predict results which deviated greatly from our experimental values, the maximum deviation being 1,000%.

The present investigation indicated influences of bed height, density of solid particles, vessel diameter and slugging on the heat transfer in contrast to the conclusions of Leva and co-workers. In the present work an increase of bed height with increasing air velocity was observed only when slugging conditions existed, whereas Leva and co-workers observed an expansion of the bed in most of their experimental runs. They calculated the mean heat-transfer coefficient on the basis of the fluidized bed at minimum voidage, which is the bed voidage at the point of incipient fluidization. This height was a fraction of the actual fluidized height observed during the experiments and of course did not change with changing gas rate as the actual height did.

The original data of Leva, Weintraub and Grummer were recalculated and compared with the present correlation as expressed by Equation (6). This comparison is shown in Figure 20. Their reported heat-transfer coefficients were recalculated on the basis of the actual bed height rather than the height at minimum voidage. Their data appear to approach our correlation at the higher Reynolds numbers. For Reynolds numbers greater than 300 the average deviation of their data from our correlation is about 35%. At the lower Reynolds numbers their data approach the relationship for air flow through an empty tube in the laminar flow region (*6*):

$$\frac{hD_t}{k_g} = 1.56\,\frac{(c_pGA)^{0.40}}{(kL)}$$

It is felt that Leva, Weintraub and Grummer's data represent conditions other than smooth, dense-phase fluidization. Apparently, their data include slugging conditions and conditions where the heat-transfer rate is not greater than to air flow through an empty tube. We were not able to correlate the data for conditions of slugging, channeling, and exceptionally low flow rates with the data for smooth fluidization. As one can observe in Figure 17 we found that conditions of slugging would reduce the heat transfer coefficient as much as 50% or more.

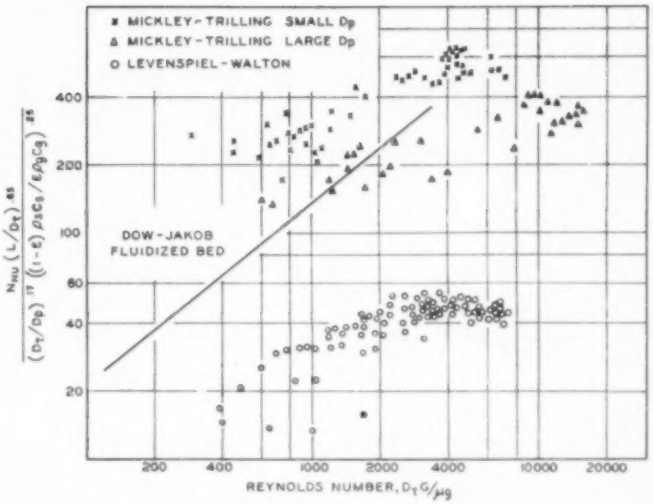


Fig. 19. Data of Mickley-Trilling and Levenspiel-Walton compared with present correlation.

Summary and Conclusions

1. The present experiments were performed with air-fluidized beds of closely sized groups of three different kinds of solids, Aerocat, coke and iron powder, of average particle sizes from 69 to 170 μ. The experiments were conducted in 2-in. and 3-in. diam. tubes and the heat input was provided by condensing steam. The investigation was limited to dense-phase fluidization with air mass velocities ranging from 60 to 305 lb.mass/(hr.)(sq.ft.).

2. The following heat-transfer mechanism for mechanically smooth fluidized beds has been conceived:

a. Transfer of heat from the tube wall to air and, by mixing, to solid particles moving downward in a narrow surface layer near the wall.

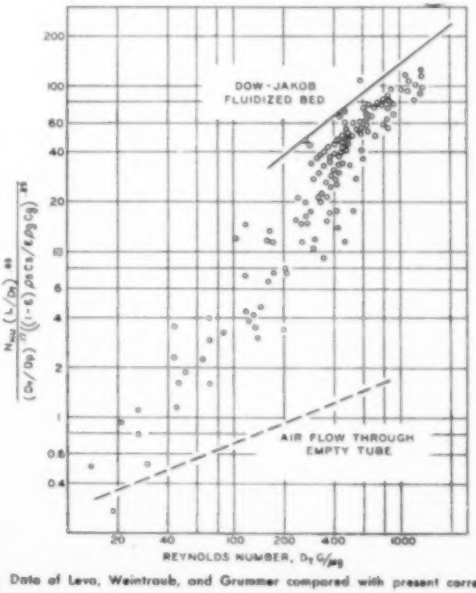


Fig. 20. Data of Leva, Weintraub, and Grummer compared with present correlation.

b. Transfer of heat in a mixing region at the bottom of the fluidized bed between the incoming cold gas and the hot particles which have fallen along the wall. Due to the enormous particle surface area available and the high heat-transfer coefficients between small particles and gases, thermal equilibrium is attained almost instantaneously in the mixing region.

c. Thermal equilibrium between the particles and the gas exists throughout the fluidized bed except in the surface layer along the wall and in the limited mixing region at the bottom of the bed.

3. The conceived heat-transfer mechism was demonstrated to be compatible with the experimental data. In particular, the heat-transfer rate from the surface to the fluidized bed was found to be independent of the thermal conductivity of the solids, and the large isothermal region of the fluidized bed could be destroyed if the downward flow of the small particles was short-circuited into the main flow before they reached the bottom, that is, under slugging conditions.

4. The experimental data were correlated according to dimensional analysis considerations and represented by empirical equations (Equations 2-6), which are valid for smooth, dense-phase fluidization of small solid particles by means of air and which fit the experimental data within the limits of ±10%.

5. The type of fluidization appears to have a marked influence on the rate of heat transfer. The present correlation does not hold under conditions of slugging or channeling which reduce the heat transfer. The data of previous workers were compared with the present correlation. Strict comparisons could not be made because previous experimenters measured local coefficients, or average coefficients over a fraction of the total bed height, or conducted their tests under conditions different than smooth, dense-phase fluidization. However, the data appear to be in qualitative agreement with the present correlation.

Acknowledgments

The authors express their sincere appreciation to Dr. J. D. Parent for having suggested the subject of this investigation and followed its progress with keen interest. The assistance of Mr. Henry Hakewill, who devised the analytical technique of measuring the apparent densities of the solid particles, and of Mr. I. B. Fieldhouse, who determined the specific heats of the solids, is gratefully acknowledged.

Notation

A = area, sq. ft.

A_w = wall area in contact with fluidized bed, sq. ft.

A_p = particle surface area, sq.ft.

C = circumference, ft.

D = diameter, ft.

D_t = diameter of solid particle, ft.

D_p = diameter of tube, ft.

G = mass velocity of arriving air = $4m/\pi D_t^2$, lb. mass/(hr.)(sq.ft.)

L = fluidized bed height, ft.

Q = heat energy, B.t.u.

T = absolute temperature, °R

V_p = particle volume, cu. ft.

a,b,c,d,e,f = constant exponents (no dimensions)

c_s = specific heat of solid particles, B.t.u./(lb. mass)(° F.)

c_g = specific heat of gas, B.t.u./(lb. mass)(° F.)

g = acceleration due to gravity, ft./(sec.)(sec.)

h = heat-transfer coefficient, B.t.u./(hr.)(sq.ft.)(°F.)

h_m = mean heat-transfer coefficient between the tube wall and the fluidized bed = $q_w/A_w(t_w - t_c)$, B.t.u./(hr.)(sq.ft.)(°F.)

k = thermal conductivity, B.t.u./(hr.)(ft.)(° F.)

k_g = thermal conductivity of gas, B.t.u. or B.t.u./(hr.)(sq.ft.)(° F./ft.)

$m = \sqrt{hC/kA}$, 1/ft. in mass rate of flow, lb. mass/hr.

q = rate of heat flow, B.t.u./hr.

q_w = rate of heat flow from tube wall to fluidized bed, B.t.u./hr.

t = temperature, °F.

t_c = core temperature of fluidized bed, °F.

t_w = tube wall temperature, °F.

u_o = velocity of gas based on the cross-sectional area of the empty tube, ft./sec.

$\alpha = k/\rho c$ = thermal diffusivity, sq.ft./hr.

μ_g = viscosity of gas, lb.mass/(hr.)(ft.)

ϵ = fraction voids in fluidized bed (dimensionless)

ρ_s = apparent density of solid particle = mass of particle divided by the volume of particle, lb.mass/cu.ft.

ρ_g = density of gas, lb. mass/cu. ft.

θ = temperature excess = $t_w - t_c$, °F.

τ = time, hr.

Dimensionless Groups

N_{Nu} = Nusselt number, $h_m D_t/k_g$

N_{Re} = Reynolds number, $D_T u_o \rho_g/\mu_g = D_T G/\mu_g$

N_{Pr} = Prandtl number, $\mu_g c_g/k_g$

Literature Cited

1. Anonymous, *Chem. Eng.*, **55**, 125 (May, 1948).
2. Boelter, L. M. K., Cherry, V. H., Johnson, H. A., and Martinelli, R. C., "Heat Transfer Notes," Univ. of California Press, Berkeley (1946).
3. Jakob, M., "Heat Transfer," Vol. I, p. 214. John Wiley & Sons, New York (1949).
4. Jakob, M., *ibid.*, pp. 278-281.
5. Jakob, M., *ibid.*, pp. 500-521.
6. Jakob, M., *ibid.*, p. 546.
7. Jakob, M., *ibid.*, p. 634.
8. Jakob, M., *ibid*, pp. 663-675.
9. Jakob, M., Erk, S., and Eck, H., *Tech. Mech. u. Thermodynam.*, **1**, 46, January, 1930.
10. Jakob, M., Erk, S., and Eck, H., *Forsch. Gebiete Ingenieurw.*, **3**, 161 (1932).
11. Jolley, L. J., *Fuel*, 28, 5:114-115, (1949).
12. Johnstone, H. F., Pigford, R. L., and Chapin, J. H., *Univ. Illinois Bull.*, 330 (June, 1941).
13. Kalbach, J. C., *Chem. & Met. Eng.* **51**, 94 (1944).
14. Kalbach, J. C., *Chem. Eng.* **54**, 105 (1947).
15. Leva, M., Grummer, M., Weintraub, M., and Pollchik, M., *Chem. Eng. Progress*, **44**, 511 (1948).
16. Leva, M., Grummer, M., Weintraub, M., and Pollchik, M., *Chem. Eng. Progress*, **44**, 619 (1948).
17. Leva, M., Grummer, M., Weintraub, M., and Storch, H. H., *Chem. Eng. Progress*, **44**, 707 (1948).
18. Leva, M., Weintraub, M., and Grummer, M., *Chem. Eng. Progress*, **45**, 563 (1949).
19. Levenspiel, O., and Walton, J. S., Heat Transfer and Fluid Mech. Inst., 1949
20. Mickley, H. S., and Trilling, C. A., meeting, 139 (May, 1949). *Ind. Eng. Chem.*, **41**, 1135 (1949).
21. Nicholson, E. W., Moise, J. E., and Hardy, R. L., *Ind. Eng. Chem.*, **40**, 2033 (1948).
22. Parent, J. D., Yagol, N., and Steiner, C. S., *Chem. Eng. Progress*, **43**, 429 (1947).
23. Ruedenberg, R., *Elektrotech. Z.*, **46**, 1344 (1925).
24. Thomas, C. L., and Hoekstra, J., *Ind. Eng. Chem.*, **37**, 332 (1945).
25. Wilhelm, R. H., and Kwauk, M., *Chem. Eng. Progress*, **44**, 201 (1948).
26. Dynamics of Fluid-Solid Systems, 15th Annual Chemical Engineering Symposium, *Ind. Eng. Chem.*, **41**, 6, 1099 (June, 1949).

(*Presented at the Heat Transfer and Fluid Mechanics Institute, Los Angeles, Calif.*)

SOLVENT DRYING

R. J. MITCHELL

California Research Corporation, Richmond, California

This paper presents a method for distillation drying of solvent mixtures such as methyl ethyl ketone and benzene which are used in wax-manufacturing processes. A design procedure is included which employs a modification of the McCabe-Thiele graphical method. Distillation of the three-component system methyl ethyl ketone-benzene-water is separated into two steps: water stripping at constant benzene composition, and benzene enrichment of a water-saturated solvent. Equilibrium data for the ternary system are given. Operating data from a commercial drier indicate plate efficiencies of 30% for the water-stripping section and 80% for benzene enrichment. The integration of such a drier into the solvent-recovery system of a wax-deoiling plant is also discussed.

IN the operation of processing equipment which utilizes methyl ethyl ketone or methyl ethyl ketone-benzene solvents, it is often desirable to control the amount of water in the solvent and, in some cases, to maintain it essentially water-free. An example of this is the manufacture of refined wax from slack wax by crystallization and filtration in the presence of these solvents. Unless the water content of the solvent used for dilution is kept low, formation of oil and wax phases in the chilling operation is unsatisfactory, hampering filtration and production of an oil-free wax. A drying system is required because water is brought into the deoiling plant with the feed, by steam stripping of wax and oil, and by leaks in coolers and steam heaters. The amount of water which may be allowed to remain in the solvent is dependent on the composition of the solvent itself. This paper presents a distillation method for removal of water from methyl ethyl ketone solvent containing some benzene or naphtha (10-30 %) to maintain less than 0.5 wt. % water in the solvent. Data for this method of drying were obtained and a drier design was incorporated into a solvent recovery system during the process design for a wax-deoiling plant which is now in operation.

Although some wax-manufacturing plants utilize pure methyl ethyl ketone as a solvent, the drying of methyl ethyl ketone alone cannot be carried out satisfactorily by distillation because the composition of the water-methyl ethyl ketone minimum boiling azeotrope is nearly the same as methyl ethyl ketone saturated with water at condenser temperatures. Complete drying must be carried out by a method such as salting out and phase separation. The presence of benzene in the solvent facilitates drying by distillation by acting as an entrainer to accomplish phase separation of an overhead distillate into a solvent and water layer. In addition, benzene aids the deoiling process. In the methyl ethyl ketone-benzene-water system, a ternary azeotrope exists as a minimum boiling mixture at 156° F. with the composition: 17.5 wt. % methyl ethyl ketone, 73.6 wt. % benzene, 8.9 wt. % water. This mixture, upon condensation, separates into two layers having the following compositions (*19*):

	Wt. % 77° F. (25° C.)	
	Upper layer	Lower layer
Methyl Ethyl Ketone	19.0	3.5
Benzene	80.6	0.1
Water	0.4	96.4

The upper layer is 91.1% by weight of the azeotrope. The phase diagram for this ternary system is shown in Figure 1 (*19*).

Methyl ethyl ketone containing from 10 to 30% benzene is suitable for crystallization of waxes from slack wax. In order to dry a solvent with this low benzene content, distillation to form the azeotrope composition for phase separation of water is neither desirable nor necessary. It was found in studying the vapor-liquid equilibria for this system that phase separation of the condensed vapors occurs well before the azeotrope is reached, because the activity coeffi-

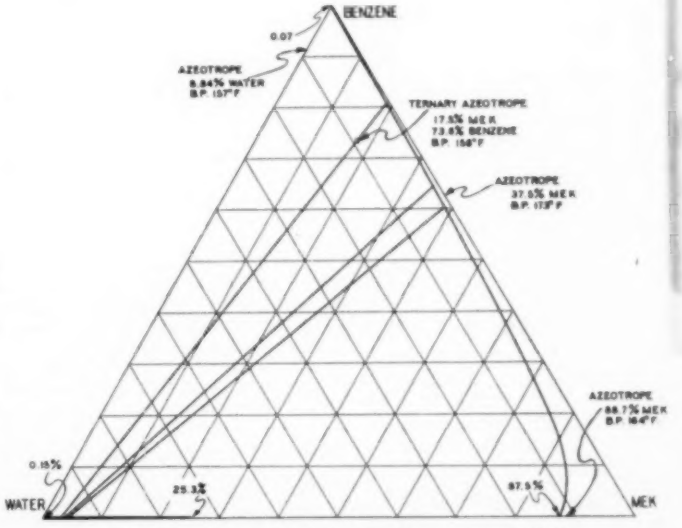


Fig. 1. Phase diagram methyl ethyl ketone-benzene-water at 77° F.

TABLE 1

VAPOR-LIQUID EQUILIBRIUM DATA
MEK-BENZENE-WATER AT ONE ATMOSPHERE

	Temp. °F	Volume, % Water	Benzene	MEK	Wt., % Water*		Temp. °F	Volume, % Water	Benzene	MEK	Lower Layer Condensed Vol. % of Total Vapor
Liquid		0.09	9.3	90.65	0.07	Liquid		4.75	9.6	85.67	
Vapor	172	0.15	10.1	89.75	0.18	Vapor	165	6.2	16.2	77.6	6
Liquid		0.27	9.3	90.45	0.32	Liquid		4.85	9.7	85.45	
Vapor	171	1.05	10.7	88.25	1.27	Vapor	163	7.9	15.7	76.4	5
Liquid		0.45	8.7	90.85	0.55	Liquid		4.90	9.2	85.9	
Vapor	170	1.57	10.0	88.43	1.65	Vapor	163	7.6	15.3	79.1	5
Liquid		0.84	8.5	90.66	1.02	Liquid		4.15	9.8	86.05	
Vapor	168	3.00	10.4	86.6	3.65	Vapor	165	6.6	15.1	80.3	5.5
Liquid		1.2	11.2	87.6	1.45	Liquid		5.6	14.7	81.7	
Vapor	166	5.3	15.2	85.5	4.00	Vapor	161.5	7.5	20.6	72.1	6
Liquid		0.8	11.2	88.0	0.97	Liquid		1.6	29.4	69.0	
Vapor	166	2.6	12.8	84.6	3.16	Vapor	161.5	5.1	34.2	60.8	4
Liquid		0.1	11.6	88.3	0.15	Liquid		1.5	50	48.5	
Vapor	170	0.6	12.7	86.7	0.72	Vapor	161	1.5+	54	44.5	-
Liquid		0.05	11.5	88.45	0.07						
Vapor	172	0.3	12.7	87.0	0.37						
Liquid		4.75	9.6	85.67	5.75						
Vapor	165	8.3	18.0	73.5	9.10						
Liquid		4.15	9.8	86.05	5.05						
Vapor	165	7.5	15.6	76.1	8.55						

*At 60°F

cient of water is so much higher than that of benzene. Formation of the azeotrope requires either a distillation column containing a large number of plates or the addition of benzene into the reflux decanter.

Azeotropic distillation involving the addition of an entrainer is the subject of several patents (*2, 8, 12, 13, 21, 22*). In general, these indicate formation of the azeotrope composition by addition of the entrainer at the top of the column or reflux drum. Distillation of heterogeneous azeotropes and the calculation of the number of theoretical plates required for an azeotropic distillation column by plate-to-plate methods are discussed in Perry (*18*). The design of azeotropic distillation columns for ternary mixtures using McCabe-Thiele graphical methods on a two-component basis is suggested by Norman (*15*), Hands and Norman (*9*), and Hodgson (*11*).

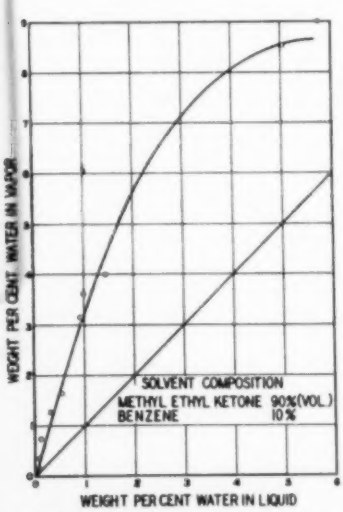

WEIGHT PER CENT WATER IN VAPOR
WEIGHT PER CENT WATER IN LIQUID
SOLVENT COMPOSITION
METHYL ETHYL KETONE 90%(VOL.)
BENZENE 10%

Fig. 2. Vapor-liquid equilibrium for water in benzene-methyl ethyl ketone.

Equilibrium Data

An Othmer-type equilibrium still (*17*) was used to determine vapor-liquid equilibria for 90% methyl ethyl ketone-10% benzene mixtures containing small quantities of water in the liquid phase. This still could not be used for higher water compositions where the vapor in equilibrium was found to form two phases upon condensation.

For equilibrium data in the region of two-phase separation of the vapor, a Gillespie still (*6*) was used with a slight change from normal operation. Before use the condensate receiver was partially filled with water saturated with methyl ethyl ketone. Sufficient solvent layer (top) for analysis was drawn off after equilibrium was reached. Immediately upon draining the condensate receiver, a running sample of the condensate was taken to obtain the relative amounts of the two phases condensed.

The equilibrium data obtained are shown in Table 1. Correction was not made for the difference in solubility of water at the still temperature and at the temperature of analysis, 68° F. (20° C.). Data are plotted in Figures 2 and 3. Figure *2* is plotted assuming essentially constant (10 vol. %) composition of benzene in the liquid. The coordinates are functions of the water concentration in liquid and vapor. Figure 3 is a plot of equilibrium for vapor and liquid saturated with water. The coordinates are functions of the benzene concentration, the activity of which is increased by the presence of water (see Fig. 4). Data are plotted in this manner for correlation and to permit use of a McCabe-Thiele plot to determine the number of theoretical steps required for distillation drying. Activity coefficients for benzene as plotted in Figure 4 are those calculated from the equilibrium data of Table 1.

Laboratory Operation

Several laboratory runs using a distillation column were made to substantiate the equilibrium data. A ¾-in. diam. insulated glass column packed with 6 ft. of ⅛-in. glass helices and equipped with a decanter at the top was used to study the actual operation of the drier. Operation of the column was carried out with a continuous feed and bottoms drawoff. The water layer from the overhead condensate was continuously separated from the solvent layer and the latter returned as reflux. Runs were made with feed points at the center of the column, one foot below the top of the packing, and 4 in. above the top of the packing. Column feed consisted of methyl ethyl ketone containing 10% benzene. Water was dissolved in the feed either to saturate it with water (approximately 5%) or to provide a 1% water content. Column reflux was measured by withdrawing a proportional part over a given time by the use of a reflux splitter.

Table *2* lists the operating conditions for four runs on this column. Figures 5 and 6 represent the McCabe-Thiele plot of equilibrium steps for runs 1 and 4. It is known from distillation data on several mixtures that one foot of packing in this column is equivalent to 5.5 theoretical plates. Operating results as represented by these plots indicate that the equilibrium data and determination of number of theoretical plates in this manner are sufficiently accurate for the design of a commercial column.

In run No. 1 (Fig. 5), the feed containing one volume per cent water (1.2 wt. %) is enriched in approximately 2½ equilibrium steps to a water-saturated composition. The reflux composition of 19.3 vol. % benzene (equivalent to approximately 18 vol. % in the overhead vapor) indicates approximately three more theoretical plates to make a total of 5½ equilibrium steps for one foot of packing height above the feed.

In run No. 4, the feed entering at the center of the column and saturated with

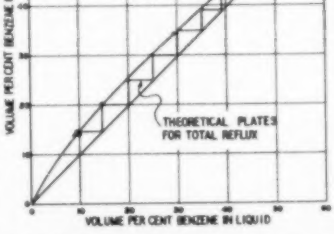


Fig. 3. Vapor-liquid equilibrium for water-saturated benzene-methyl ethyl ketone.

water is enriched in benzene to 54 vol. % in the overhead vapor (58 vol. % in reflux). The enrichment is carried out in 16.5 theoretical steps in the 3 ft. of packing height above the feed (see Fig. 6).

In runs 2 and 3, feed points are not in the correct locations for accurate representation by a McCabe-Thiele plot. They are presented to show the effect of reflux ratio. Run 3 at an $L/V = 3.0$ does not provide a dry product with 6 ft. of packing below the feed.

Compositions of all equilibrium and distillation samples from laboratory runs were obtained by specific gravity and refractive index determinations. Methyl ethyl ketone and benzene used were C.P. grade and standard samples were made up for the methyl ethyl ketone-benzene-water system.

Commercial Column Operating Conditions

Solvent feed to a commercial column generally varies considerably in water content. In addition to the variable amounts of water which may be picked up from the plant feed, water leakage into the system may put a maximum load on the column at a time when it is desirable to operate the deoiling plant for a limited period before shutdown.

In order to keep the water content of the solvent as low as possible without an excessive number of plates, an L/V ratio of 2.0 below the feed is a design requirement. Table 3 lists actual operating results for a 30-plate commercial column in which the main (damp) feed is introduced at the 15th tray from the bottom and the wet feed at the 25th tray. Normally the main feed to this drier comes from flash columns where solvent is recovered from the oil and wax. This feed usually contains less than one per cent water. The wet feed is a water-saturated solvent decanted from steam-stripper condensate and makes up less than five per cent of the total feed.

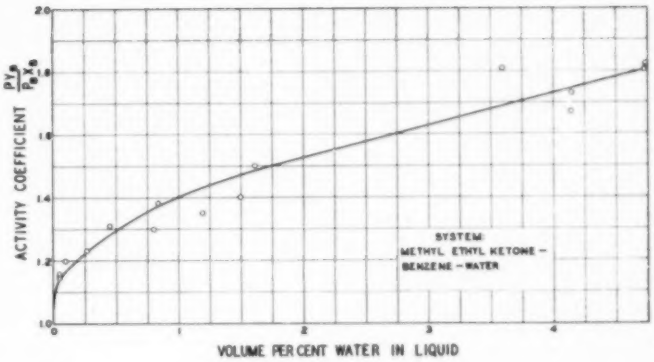


Fig. 4. Activity coefficient of benzene.

TABLE 2

OPERATING DATA – LABORATORY COLUMN

Run No.	Feed Composition (Vol. %) MEK	Benzene	Water	Feed Point	Reflux Composition (Vol. %) MEK	Benzene	Water	L/V Below Feed	L/V Above Feed	Wt. % Water in Liquid 12 In. From Top	36 In. From Top	Column Bottoms
1	89.1	9.9	1.0	12 in. from top	80.1	19.3	0.6	2.0	0.95	-	<0.1	<0.1
2	89.1	9.9	1.0	4 in. above packing	85.8	13.7	2.5	1.9	-	0.72	< 0.1	<0.1
3	89.1	9.9	1.0	4 in. above packing	82.0	15.8	2.2	3.0	-	Two Phases	Two Phases	0.4
4	85.5	9.5	5.0	36 in. from top	40.5	58	1.5	2.0	0.98	-	-	<0.1

Test numbers 2 and 3 represent normal operating conditions in which the main feed contained 0.19 wt. % water. The other tests cover a period during which the water content of the solvent was abnormally high. Determination of the water content in test run samples was carried out by a modified Karl Fischer method (*14*). Benzene compositions were obtained by direct volumetric measurement after absorption of the ketone with sodium bisulfite solution.

Since two-phase separation of the distillate occurs at low benzene compositions, it is not necessary to design a column to enrich the overhead in benzene. The main function of the column is that of a stripping section to provide a dry bottoms product and a water-enriching section to form a two-phase overhead condensate. Operating data show that plate efficiencies of 30% are obtainable. Figure 7 is a McCabe-Thiele plot of the stripping section below the main feed for test No. 3 and Figure 8 is a plot for water enrichment above the feed. An equilibrium line drawn at 30% Murphree plate efficiency satisfies the stepwise calculation of a total of 25 trays, 15 for the stripping section ($L/V = 2.0$) and 10 for the water-enriching section, where the reflux ratio is essentially 0.99. Since the overhead for this test run is enriched in benzene (31.6 vol. % in reflux), by referring to Figure 3 it is seen that four equilibrium steps are required to enrich from 10 to 30% benzene. At 80% efficiency the additional five trays in the column are accounted for. Similar study of the other

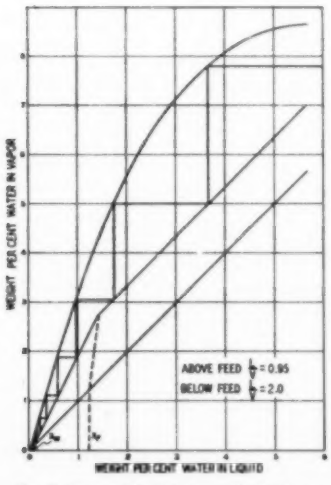


Fig. 5. Test run No. 1—⅞ in. packed column.

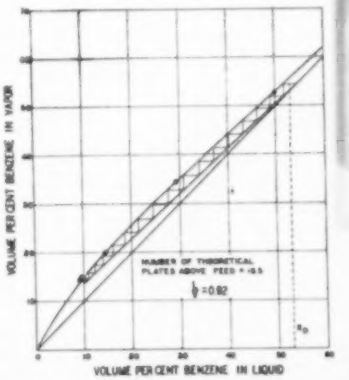


Fig. 6. Test run No. 4—⅞ in. packed column; enriching section.

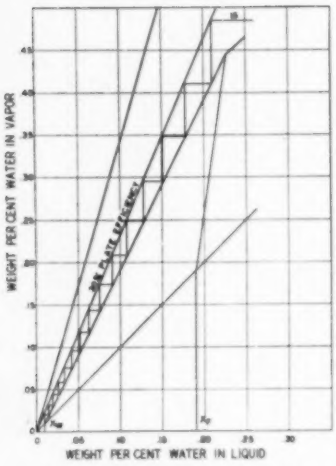


Fig. 7. Commercial column—Test No. 3, stripping section.

TABLE 3

OPERATING DATA FOR 30 PLATE COMMERCIAL COLUMN

Test No.	Steam Rate Lbs./Hr.	L/V at Re-boiler	Dump Feed Rate Bbls./Hr.[1]	Dump Feed wt.% H_2O	Dump Feed Vol. % Benzene	Wet Feed Rate Bbls./Hr.[1]	Wet Feed wt.% H_2O	Wet Feed Vol. % Benzene	Bottoms Product wt. % H_2O	Bottoms Product Vol. % Benzene	Reflux Rate Bbls./Hr.[1]	Reflux wt.% H_2O	Reflux Vol. % Benzene	Water Separated, Gals./Hr. Calculated	Water Separated, Gals./Hr. Measured[2]
2	5500	2.58	90	0.19	9.2	5	4.9	15.8	0.06-0.07	9.8	50	3.00	30.2	34.3	42.5
3	6100	2.0	104	0.29	9.0	3	4.75	17.5	0.02-0.08	10.1	45	2.84	31.6	41.7	8.7
4	4800	2.27	97	1.50	8.2	3	4.9	13.4	0.2-0.25	-	37	1.9	40.4	48.1	58.6
5	2800	2.68	98	1.75	8.0	3	5.7	20.2	0.9-1.1	-	20	1.5	47.0	51.0	49.3
6	5400	1.94	100	2.74	7.7	5	5.2	19.2	0.11-0.10	-	55	1.2	50.0	105	127.5
7	6950	1.90	95	4.57	7.7	3.5	5.1	14.0	1.51-1.58	-	58	1.0	56.7	140	104

[1] U. S. gallons at 60°F

[2] Includes dissolved solvent.

data for this column confirms the 30% tray efficiency for the water-stripping and enriching sections. In test No. 7 where the feed is essentially saturated with water, enrichment in benzene from 8% to 56.7% (reflux) is carried out with a plate efficiency of 80%. Some enrichment in benzene is desirable to reduce the water content of the reflux and to obtain sharp phase separation in the condensate decanter.

The actual plate efficiencies for water-stripping and enriching sections are less than those which can be calculated by the method of Geddes (*4*). Plate efficiencies calculated by this method are in the range of 50-60%. Vapor and liquid diffusion coefficients utilized for these calculations were determined by the methods of Sherwood (*20*) and Arnold (*1*), respectively. The accuracy of the coefficients does not permit a more exact comparison of plate efficiencies. Efficiencies predicted by the correlations of Drickamer and Bradford (*3*) and O'Connell (*16*) are also about the same as those calculated by Geddes' method. The work of Gester (*5*), however, showed that for the high relative volatilities involved in dehydrating hexane actual efficiencies are about 25% of those calculated by the method of Geddes. Results of this work guided the selection of plate efficiencies in the design of the distillation drier described here.

The plate efficiency obtained when enriching in benzene is, on the other hand, higher than that obtained by Geddes' method even if liquid diffusion is neglected. An efficiency of 60% was calculated whereas an 80% efficiency was realized in the commercial column. This high efficiency is the reverse of what would be expected for lower L/V ratios ($L/V = 0.99$) when compared to the water-stripping section ($L/V = 2.0$). It can be accounted for qualitatively by the lower relative volatility between benzene and methyl ethyl ketone compared with that between water and the solvent mixture.

Other investigations (*7, 10*) have reported plant column efficiencies of about 25% for hydrocarbon extractive distillation with furfural. They also were unable to make accurate quantitative predictions of plate efficiencies using the method of Geddes.

The McCabe-Thiele method of calculation was checked by plate-to-plate calculations using the variable activity for benzene throughout the column. The activity of benzene is low compared with that for water, which is essentially constant over a wide range of solvent compositions. Therefore, the analysis as two separate two-component systems is satisfactory for design purposes.

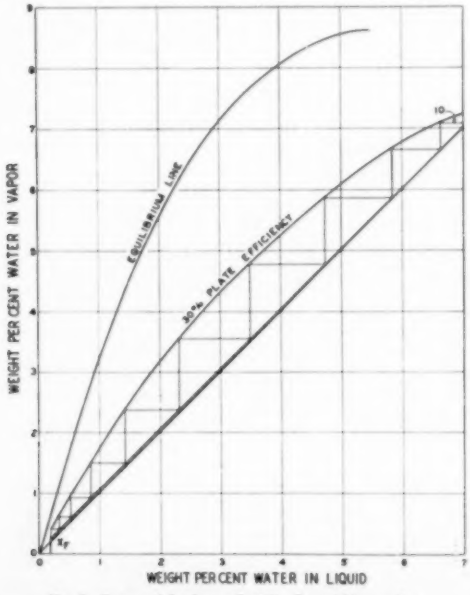


Fig. 8. Commercial column—Test No. 3, enriching section.

Application of Solvent Drying

Figure 9 shows a typical application of solvent drying as a part of a wax-deoiling plant solvent-recovery system. Figure 10 is a photograph of the installation showing the solvent drier, the largest column, located in the center of the solvent-recovery equipment. The main feed to the drier is taken from the low-pressure flash columns which contain approximately 80% of the water in the solvent. The amount of wet solvent

recovered from the oil and wax strippers and ketone fractionator is normally small compared with the main feed. The solvent is stripped dry and removed from the bottom of the drier. The overhead phases are separated and the solvent layer returned as reflux to the column. The water phase which contains dissolved solvent is fed to the ketone fractionator along with the decanted water from condensed vapors from the oil and wax strippers. Last traces of solvent are steam-stripped from the water in this column. This arrangement permits operation of the drier on automatic control with a manually set steam rate to the reboiler.

This process is the subject of patent applications of California Research Corp.

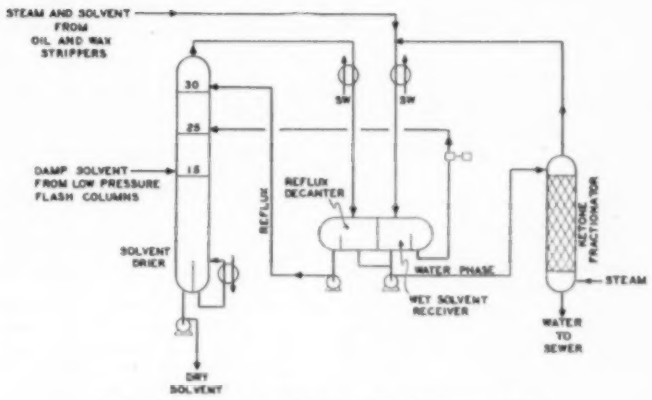


Fig. 9. Solvent drying in a wax-deoiling plant solvent-recovery system.

Acknowledgment

The author wishes to express his appreciation to E. M. Blue and E. B. Chiswell under whose supervision this work was done, and to his associates for valuable assistance, in particular to R. L. LeTourneau for his contribution in the analytical phases of the work.

Notation

L = liquid rate, lbs./hr.
P = total pressure, lbs./sq.in., abs.
P_B = vapor pressure of pure benzene, lbs./sq.in., abs.
V = vapor rate, lbs./hr.
X = composition of liquid, consistent units
X_D = distillate composition
X_F = feed composition
X_W = bottoms composition
Y = composition of vapor, consistent units

Literature Cited

1. Arnold, J. H., *J. Am. Chem. Soc.*, **52**, 3937 (1930).
2. Deanesly, R. M., U. S. Patent 2,290,636 (July 21, 1942).
3. Drickamer, H. G., Bradford, J. R., *Trans. Am. Inst. Chem. Engrs.*, **39**, 319 (1943).
4. Geddes, R. L., *Trans. Am. Inst. Chem. Engrs.*, **42**, 79 (1946).
5. Gester, G. C., Jr., *Chem. Eng. Progress*, **43**, 117 (1947).
6. Gillespie, D. T. C., *Ind. Eng. Chem., Anal. Ed.*, **18**, 575 (1946).
7. Grohse, E. W., McCartney, R. F., Hauer, H. J., Gerster, J. A., and Colburn, A. P., *Chem. Eng. Progress*, **45**, 725 (1949).
8. Guinot, H. M., and Ricard, E., U. S. Patent 1,862,706 (June 14, 1932).
9. Hands, C. H. G., and Norman, W. S., *Trans. Inst. Chem. Engrs. (London)*, **23**, 76 (1945).
10. Happel, J., Cornell, P. W., Eastman, DuB., Fowle, M. J., Porter, C. A., and Shutte, A. H., *Trans. Am. Inst. Chem. Engrs.*, **42**, 189 (1946).
11. Hodgson, M. A. E., *Research (London)*, **1**, 568 (1948).
12. Jenkins, V. N., U. S. Patent 2,397,868 (April 2, 1946).
13. Kraft, W. W., U. S. Patent 2,017,067 (Oct. 15, 1935).
14. Mitchell, J., Jr., and Smith, D. M., "Chemical Analysis," Vol. 5 (Aquametry), Interscience Publishers, Inc., New York, 151-155 (1948).
15. Norman, W. S., *Trans. Inst. Chem. Engrs. (London)*, **23**, 66 (1945).
16. O'Connell, H. E., *Trans. Am. Inst. Chem. Engrs.*, **42**, 741 (1946).
17. Othmer, D. F., *Ind. Eng. Chem.*, **20**, 743 (1928); **35**, 614 (1943).
18. Perry, J. H., "Chemical Engineers' Handbook," 3rd Ed. McGraw-Hill Book Co., New York, 631, 652 (1950).
19. Shell Union Oil Co., "Methyl Ethyl Ketone" (1938).
20. Sherwood, T. K., "Absorption and Extraction," McGraw-Hill Book Co., New York, 14-19 (1937).
21. Shiffler, W. H., and Mithoff, R. C., U. S. Patent 2,000,043 (May 7, 1935).
22. Van Peski, A. J., and Smithuysen, W. C. B., U. S. Patent 2,050,513 (Aug. 11, 1936).

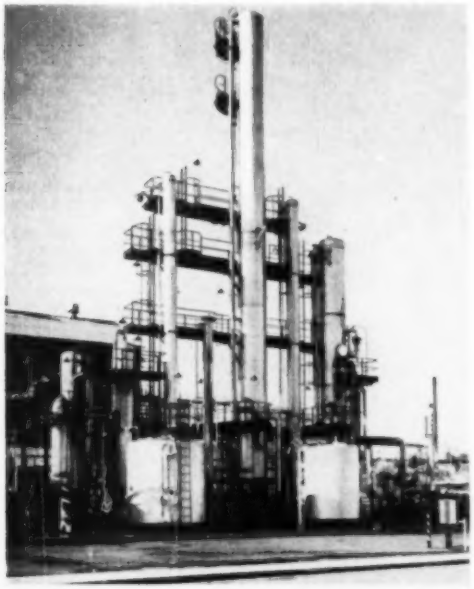


Fig. 10. Wax plant—solvent-recovery equipment with solvent drier (large column).

(Presented at Rochester (N. Y.) Meeting.)

CAST ALLOY REFERENCE SHEET

N. S. MOTT, Chief Chemist Metallurgist
The Cooper Alloy Foundry Co., Hillside, N. J.

ALLOY: CORROSION RESISTANT LOW CARBON 25% CHROMIUM 12% NICKEL ALLOY.

APPLICATIONS AND REMARKS: Alloy type 25-125 gives improved resistance over 18-8S due to its higher chromium and nickel contents, and is used for more exacting corrosive applications which are not severe enough to warrant the use of more expensive alloys. For example, it is about four times as resistant to hot weak sulfuric acid as 18-8S. In other corrosives the improvement is also found in varying degrees. As the chromium content is considerably higher than 18-8S, there is not such an extreme in the tendency toward intergranular corrosion and higher carbon contents may be tolerated. It is cast into a wide variety of shapes at an increase of 7 cents/lb. over 18-8S.

DESIGNATIONS: ACI CH-10; AISI 309S; ASTM A296-49T, Grade CH10.

CHEMICAL COMPOSITION RANGE: C < .10%; Cr 22-26%; Ni 12-15%; Si < 2%.

MACHINABILITY: 25-12S is tough, ductile, and is characterized by its work-hardening and high-frictional properties. Best results for turning are obtained by using a slow, heavy cut. To avoid work-hardening the surface care should be taken not to allow the tool to ride or glaze the work. Sharp tools with a large rake are desirable and chip-curler tools are recommended.

HEAT TREATMENT: For the best in corrosion resistance 25-12S is water quenched from 1950-2050° F. after holding from 1 to 3 hrs. depending upon thickness.

WELDABILITY: For corrosion resistance this alloy should be welded with a similar composition welding rod. All the usual methods may be used. Intergranular corrosion tendency due to carbide precipitation is somewhat obviated but not completely eliminated by its higher chromium content. For the best corrosion resistance therefore the work should be water-quenched from 1950 - 2050 ° F. after welding.

MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, 1000 lb./sq.in.	80	Melting Point	2550-2650° F.
Yield Point, 1000 lb./sq.in.	45	Specific Heat (B.t.u./(lb.)/° F.) 32-212° F.	0.14
Elongation, %	40	Thermal Expansion (× 10⁻⁶ in./(in.)/° F.) 32-212° F.	8.3
Reduction in Area, %	45	Thermal Conductivity (B.t.u./(hr.)(sq.ft.)(° F./in.)) 32-212° F.	104
Brinell Hardness	160	Electrical Resistance (Ohms./cir. mil. ft.) @ 32° F.	480
Charpy Impact (Std. Keyhole ft.lbs.)	70		
Mod. of Elasticity (× 10⁶ lb./sq.in.)	28		
Specific Gravity	7.73		

CORROSION RESISTANCE

ACIDS	
Acetic 5%, 70 F	E
Acetic 5%, boiling	E
Acetic 80%, 70 F	E
Acetic 80%, boiling	F
Acetic Glacial, 70 F	E
Acetic Glacial, boiling	F
Benzoic 5%, 70 F	E
Boric 5%, 176 F	E
Chromic 10%, 70 F	E
Chromic 10%, boiling	F
Chromic 50%, boiling	P
Citric 5%, 70 F	E
Citric 25%, boiling	G
Citric 50%, boiling	F
Formic 5%, 70 F	G
Hydrochloric 1%, 70 F	F
Hydrochloric 1%, boiling	N
Hydrochloric, 5%, 70 F	N
Hydrochloric 5%, boiling	N
Hydrochloric 25%, 70 F	N
Hydrochloric 25%, 176 F	N
Hydrofluoric 48%, 70 F	P
Hydrofluoric 48%, 176 F	N
Lactic 5%, 70 F	E
Malic, all temps.	E
Nitric all concs., 70 F	E
Nitric 65%, boiling	E
Oleic all concs., all temps.	E†
Oxalic 5%, boiling	E
Phosphoric 10%, 70 F	E
Phosphoric 85%, 70 F	E
Phosphoric 85%, boiling	N
Stearic concentrated to 200 F	E
Sulfuric 2%, 70 F	G
Sulfuric 2%, 176 F	F
Sulfuric 2%, boiling	P
Sulfuric 5%, 70 F	G
Sulfuric 5%, 176 F	F
Sulfuric 5%, boiling	N
Sulfuric 10%, 70 F	F
Sulfuric 10%, 176 F	P
Sulfuric 10%, boiling	N
Sulfuric 78% (60° Be), 176 F	N
Sulfuric 93% (66° Be), 70 F	E
Sulfuric 93%, 300 F	N
Oleum, 70 F	G
Mixed Acids 57% H_2SO_4, 28% HNO_3, 176 F	E
ALKALIES	
Ammonium Hydroxide, all concs.	E
Calcium Hydroxide Sat., 70 F	E
Calcium Hydroxide Sat., boiling	F
Sodium or Potassium, Hydroxide, all concs., 70 F	E
Sodium or Potassium Hydroxide < 20%, boiling	E
Sodium or Potassium Hydroxide 30% boiling	F
Sodium or Potassium Hydroxide, Molten, 600 F	N
NEUTRAL AND ALKALINE SALTS	
Barium Sulfide, 70 F	G
Calcium Chloride 5%, 70 F	G†
Calcium Sulfate Sat., 70 F	E
Magnesium Chloride 5%, 70 F	G†
Magnesium Sulfate 5%, 70 F	E
Sodium Carbonate, all concs., 70 F	E
Sodium Chloride 5%, 70 F	G†
Sodium Sulfate 5%, 70 F	E
Sodium Sulfide 5%, 70 F	E
Sodium Sulfite 5%, 70 F	G
ACID SALTS	
Alum 10%, boiling	G†
Aluminum Sulfate 10%, 70 F	G†
Ammonium Chloride 5%, 70 F	G†
Ammonium Sulfate 10%, 70 F	G
Ammonium Sulfate 10%, boiling	F†
Ammonium Nitrate, all concs., 70 F	E
Stannous Chloride 5%, 70 F	F†
Zinc Chloride 5%, boiling	P†
OXIDIZING ALKALINE SALTS	
Calcium Hypochlorite 2%, 70 F	F†
Sodium Hypochlorite 5%, 70 F	F†
Sodium Peroxide	E
OXIDIZING ACID SALTS	
Ammonium Persulfate 5%, 70 F	E
Cupric Chloride 1%, 70 F	P†
Cupric Sulfate 10%, 70 F	E
Ferric Chloride 10%, 70 F	P†
Ferric Sulfate, boiling	G
Mercuric Chloride 2%, 70 F	P†
Stannic Chloride 5%, 70 F	P†
WET AND DRY GASES	
Chlorine Gas Dry, 70 F	G
Chlorine Gas Wet, 70 F	N
Sulfur Dioxide Dry, 575 F	E
Sulfur Dioxide Wet, 70 F	G†
Sulfur Dioxide Solution, 70 F	F†
Sulfur Dioxide Spray, 70 F	P†
Hydrogen Sulfide Dry	E
Hydrogen Sulfide Wet	G
ORGANIC MATERIALS	
Acetone, 70 F	E
Acid Sludge (50% H_2SO_4), 200 F	N
Alcohol—Methyl and Ethyl	E
Aniline Hydrochloride, 70 F	N
Benzol, 176 F	E
Carbon Tetrachloride	E
Chloroform	E
Ethyl Acetate, 70 F	E
Formaldehyde, 70 F	E†
Phenol 5%, boiling	E†
Refinery Crudes	F
Trichlorethylene, boiling	E
PAPER MILL APPLICATIONS	
Kraft Liquor	E
Black Liquor	E
Green Liquor	E
White Liquor	E
Sulfite Liquor, 176 F	G†
Chloride Bleach	F†
Paper Makers Alum	G
PHOTOGRAPHIC INDUSTRY	
Humid Atmospheres	E
Cellulose Acetate	G
Acetic Anhydride	G
Acetic Acid + 1% H_2SO_4	P
Developers	E
Solutions Containing SO_2	F
Silver Nitrate, 70 F	E
FERTILIZER MANUFACTURING	
$H_3PO_4 + H_2SO_4 + HF$	P
PICKLING OPERATIONS	
H_2SO_4 + Dichromate, 176 F	G
H_2SO_4 + Hcl, 176 F	N
CORROSIVE WATERS	
Acid Mine Water	E†
Abrasive Acid Mine Water	P
Sea Water	G†
Brackish Water	G†
FOOD & ASSOCIATED PRODUCTS	
Brines	G†
Edible Oils	E
Fats	E
Fatty Acid Distillation	E
Fruit Juices	E
Ketchup	G†
Milk Pasteurizing	E
Vinegar and Salt, 70 F	G†

RATINGS:

E—Excellent resistance. 0.001 max. in. per year of penetration. Corrosion so slight as to be harmless.
G—Good resistance. 0.001-0.012 in. per year of penetration. Satisfactory service expected; at most a slight etch.
F—Fair resistance. 0.012-0.120 in. of penetration per year. Satisfactory service under specific conditions. Light to moderate attack.
P—Poor resistance. 0.120-0.320 in. of penetration per year. Satisfactory for temporary service only.
N—No resistance. 0.320 min. in. of penetration per year. Rate of attack too great for any use.
†—Subject to pitting type corrosion.

No. 6
(SIXTH OF A SERIES OF TEN)

CHEMICAL ENGINEERING PROGRESS

◇

Volume 47

1951

◇

Editorial Staff

H. R. GLENNON — *Editor*, F. J. VAN ANTWERPEN — H. PITTIS

M. KAYMORE — J. B. DURAR — C. A. KING

Advertising Staff

Advertising Manager, L. T. DUPREE

R. R. QUINN — E. C. VICKERY — S. J. CHICK

R. P. McKEY — P. A. JOLCUVAR — W. E. COATES, SR.

G. O. JACOBSEN

Circulation Staff

R. M. GILL — E. M. CARGILL — TOD M. PRITCHARD

C. A. SPOSATO

◇

Published by

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

120 East 41st Street, New York 17, N. Y.

OFFICERS OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

1951

President
T. H. CHILTON

Vice-President
W. I. BURT

Secretary
STEPHEN L. TYLER

Treasurer
C. R. DeLONG

Directors

Donald B. Keyes
Paul D. V. Manning
Irvin L. Murray
H. Dayton Wilde

George E. Holbrook
Chalmer G. Kirkbride
R. Lindley Murray
Walter G. Whitman

Robert C. Gunness
R. Paul Kite
Charles R. Nelson
Earl P. Stevenson

CHEMICAL ENGINEERING PROGRESS

Vol. 47—1951

AUTHORS' INDEX

Editor's Note: Page numbers preceded by the number of the issue (No. 1, No. 3, etc.) indicate that the article is in the New section of that issue.

A

Adler, C. R. 515, 601
Alexander, L. G. 181
Altpeter, R. J. 243
Armstrong, W. P. 405
Askins, J. W. 401

B

Baker, A. H. 205
Ballou, C. O. 199
Baron, Seymour 473
Baron, Thomas 181
Beek, John, Jr. 534
Benedict, Manson, 51, 111, 419, 449, 571, 609
Berg, Clyde 11, 585
Berg, Lloyd 283, 469
Bernard, R. A. 101
Beychok, M. R. 265
Bliss, Harding 529
Boas, Arnold 51, 111
Bogash, Richard 347
Bollens, W. F. 443
Bonnet, W. E. 151, 523, 621
Boraks, H. E. 385
Bowles, R. R. 309
Bowman, J. R. 63, 123
Bradford, Purdy 443
Braidech, M. W. 595
Brown, G. G. ..... No. 3: 46
Buckley, R. A. 243
Bullock, H. L. 397
Busche, R. M. 29
Butterworth, J. W. 591
(Abstr. article in "C.E.P." Symposium Series No. 1)

C

Caddell, J. R. 333
Cannon, M. R. 344, 565
Carlin, Benson 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Carpenter, C. LeRoy 211
Chambers, J. M. 555
Charlesworth, D. H. 566
Chilton, T. H. 1, 593
Chu, Ju Chin 29
Cichelli, M. T. 63, 123
Clark, E. L. 392, 455
Coberly, C. A. 141, 507
Comings, E. W. 175, 223
Crawford, J. W. 423
Curtis, F. J. 49

D

Dart, J. C. 95
Deanesly, R. M. 134
De Vaut, A. W. 443
Dow, W. M. 637

E

Ebel, R. A. 405, 628
Edmister, W. C. 191

F

Farwell, S. P. 219
Fitch, E. B. 83
Friend, Leo 571, 609
Fuhrmeister, Charles, Jr. 550

G

Gamson, B. W. 19
Garwin, Leo 186
Gates, R. M. ..... No. 5: 30
Gerster, J. A. 151, 523, 621
Gilliland, E. R. ..... No. 1: 11; 251
Goss, W. H. 489
Grace, H. P. 502
Grimmett, H. L. 175
Guess, A. P. 339
Gullekson, E. E. 309
Gunness, R. C. 331

H

Hauck, C. F. 376
Heinlein, A. C. 344, 565
Hiedemann, E. A. 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Hess, Irwin 523, 621
Hinds, G. P., Jr. 401
Hippely, P. R. 283
Hiteshue, R. W. 392, 455
Hixson, A. N. 347
Hobson, Merk 370
Hoffing, E. H. 3
Hougen, J. O. 295
Hougen, O. A. 528
(Abstr. article in "C.E.P." Monograph Series No. 1
Hubbard, J. C. 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Hueter, T. F. 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Hurt, D. M. 333

I

Irvin, H. B. 287

J

Jakob, Max 637
Joffe, Joseph 80
Jones, R. W. 46

K

Kandiner, H. J. 392, 455
Katz, D. L. 317
Kemp, H. S. 339
Kern, D. Q. 211
Kiang, C. T. 405
Kieweg, Homer 341
Kindschy, E. O. 469
Knight, G. B. 385
Kobe, K. A. ..... No. 9: 48
Kunreuther, Frederick 401
Kylander R. L. 186

L

Larson, M. W. 270
Lenoir, J. M. 223
Leva, Max 39
Lewis, W. K. 251
Lockhart, F. J. 3
Lundberg, L. A. 257
Lyon, R. N. 75

M

MacDonald, R. W. 363
McCabe, W. L. 91, 168
McCarthy, F. S. 102
McCarthy, J. L. 257
Maerker, J. B. 95
Manders, Martin 11
Manning, R. E. 344, 565
Marshall, W. R., Jr. 141, 507, 515, 601
Martin, J. J. 91
Meissner, H. P. 579
Miller, A. L. 107
Miller, P. C. 107
Miller, R. A. 205
Miller, S. A. 497
Miner, H. L. 598
Minevitch, J. R. 385
Mitchell, R. J. 649
Monrad, C. C. 91
Morris, G. A. 232
Morse, R. D. 199
Mott, N. S. 382, 440, 494, 542, 592, 654
Mullen, L. T. 339
Munger, H. P. 436

N

Neumann, E. P. 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Niven, W. W., Jr. ..... No. 3: 17; No. 4:17
Norton, J. L. 528
(Abstr. article in "C.E.P." Symposium Series No. 1)

Pages by months: January, 1-48; February, 49-104; March, 105-158; April, 159-214; May, 215-274; June, 275-330; July, 331-382; August, 383-440; September, 441-494; October, 495-542; November, 543-592; December, 593-654

O

O'Donnell, R. J. ... 309
Olson, R. W. ... 287
Osberg, G. L. ... 566

P

Pearson, D. A. ... 257
Perry, Eli ... 354
Pierce, J. E. ... 432
Piret, E. L. ... 295, 363, 405, 628
Potter, Charles ... 473
Praschan, V. C. ... 325

R

Reese, F. E. ... 354
Reid, R. C. ... 415
Reveal, W. S. ... 283, 469
Robinson, D. B. ... 317
Root, S. E. ... 385
Rubin, F. L. ... 541
Rubin, L. C. ... 419, 449, 571, 609
Rushton, J. H. ... 485

S

Saeman, W. C. ... 508
Samsel, R. W. ... 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Sanders, M. D. ... 443
Saner, H. A. ... 469
Schall, J. W. ... 95
Scoville, L. P. ... No. 12: 52
Seferian, Ralph ... 579
Selke, W. A. ... 529
Siller, Irving ... No. 8: 17
Silverman, Leslie ... 462
Singer, Emanuel ... 534
Sittenfield, Marcus ... 481
Smith, E. G. ... 545
Smith, J. M. ... 287, 415
Sollner, Karl ... 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Souders, Mott, Jr. ... 383
Stephens, E. J. ... 232
Stevens, R. P. ... 168
Stevenson, E. P. ... 159
Stokes, C. A. ... 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Stout, L. E. ... 29
Sweeney, M. P. ... 251
Switzer, Robert ... 11

T

Taylor, J. F. ... 175
Thodos, George ... 370
Thompson, A. R. ... 304
Tursi, R. R. ... 304
Tyler, Chaplin ... 217

V

Vail, J. G. ... 105
Van Antwerpen, F. J. ... 441, 495, 543
Vivian, J. E. ... 528
(Abstr. article in "C.E.P." Symposium Series No. 1)

W

Watkins, C. H. ... 134
Weatherford, W. D., Jr. ... 63, 123
Weaver, J. B. ... No. 2: 17
Webb, G. B. ... 419, 449, 571, 609
Weinberg, A. M. ... No. 3: 19
Weissler, Alfred ... 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Wentworth, R. L. ... No. 12: 18
West, F. B. ... 257
Wilde, H. D. ... No. 9: 17; 215
Wiley, R. M. ... 432
Wilhelm, R. H. ... 101, 493
Wilke, C. R. ... 423
Williams, W. H. ... 277

A.I.Ch.E. ACTIVITIES

Awards:
- A. McLaren White ... No. 12: 17
- Best Presented Paper ... No. 1: 15; No. 4: 20; No. 6: 22; No. 10: 20
- Junior ... No. 12: 17
- Professional Progress in Chemical Engineering ... No. 1: 11; No. 10: 24; No. 12: 17
- W. H. Walker ... No. 12: 17

Committees:
- Accrediting ... No. 1: 17; No. 3: 46
- Chem. Eng. Educ. Projects ... No. 9: 48; No. 10 48
- Professional Legislation ... No. 2: 26; No. 7: 33
- Publication ... No. 1: 1

Council's Report ... No. 2: 32

Lecture
No. 1: 20; No. 10: 24; No. 12: 17

Local Sections—No. 1: 36; No. 2: 47; No. 3: 30, 48; No. 4: 46; No. 5: 44; No. 6: 46; No. 7: 39; No. 8: 24, 38, 40; No. 9: 50; No. 10: 57; No. 11: 73; No. 12: 50, 52

Meetings:
- Atlantic City: No. 5: 42; No. 10: 17; No. 11: 19
- Columbus ... No. 1: 15
- Kansas City ... No. 3: 17; No. 4: 17; No. 6: 17
- Rochester ... No. 7: 13; No. 8: 17; No. 10: 20
- White Sulphur Springs ... No. 1: 11, 13; No. 2: 18; No. 4: 20

Secretary's Report ... No. 2: 41; No. 3: 45; No. 4: 45; No. 5: 34; No. 6: 43; No. 7: 37; No. 8: 38; No. 9: 40; No. 10: 42; No. 11: 73; No. 12: 48

Student Chapters ... No. 4: 48; No. 6: 49; No. 12: 52

Suspense List ... No. 2: 28

Treasurer's Report ... No. 5: 33

SUBJECT INDEX

A

Absorption, Determination of Liquid-Film Coefficients ... 232
- On a Semi-Works Scale ... 257

Accident Prevention (also see Safety) ... 595, 598

Acid Recovery Units, Construction of ... 339

Accrediting (see A.I.Ch.E. Committees)

Adsorption ... 585

Agitation ... 317
- Continuous Flow Stirred Tank Reactor Systems ... 363
- Graphical Analysis of Continuous Reactions in Series of Agitated Vessels ... 46

American Chemical Society—No. 1: 42; No. 8: 44; No. 9: 26

American Society Engineering Education—No. 7: 22; No. 8: 21

American Society Testing Materials—No. 11: 23

American Standards Association—No. 2:46; No. 3: 23; No. 6: 26; No. 8: 22; No. 11: 22

Atomic Energy (see Atomic Energy Commission)

Atomic Energy Commission—No. 1: 22; No. 2: 26; No. 3: 19, 26; No. 4: 32; No. 5: 31, 40; No. 6: 26, 40; No. 7: 34; No. 10: 33; No. 11:21; No. 12:24, 28, 44

Atomization; Performance of Spinning Disk Atomizers ... 515, 601

Autothermic Cracking; Production of Ethylene by ... 134

Awards (see A.I.Ch.E. Committees) (see also Medals)

B

Benzene (see Catalysis)

Boiling Coefficients (see Transfer, Heat)

Book Reviews—
- Analytical Chemistry of Manhattan Project—Rodden (Ed.), No. 3: 34
- Applied Nuclear Physics—Pollard and Davidson ... No. 3: 34
- Beet Sugar Technology—McGinnis ... No. 10: 30
- Behavior of Engineering Metals—Gillett ... No. 5: 28
- Chemical Engineering Cost Estimation—Aries and Newton, No. 1: 30
- Chemical Engineering for Production Supervision—Pierce, No. 7: 24

Chemical Facts and Figures—Mfg. Chemists' Assoc., Inc., No. 3: 32
Chemical Who's Who—Haynes and Downs (Eds.)....No. 6: 30
Chemistry of Nonbenzenoid Hydrocarbons—Brooks, No. 2: 30
Condensed Chemical Dictionary Turner (Ed.); Revised by Arthur and Elizabeth Rose...No. 3: 42
Crystal Growth—Buckley. No. 5: 28
Distillation Equilibrium Data—Chu, and Associates..No. 3: 32
Engineering Method—Fish, No. 5: 28
Fertilizer Grade Ammonium Nitrate—Mfg. Chemists' Assoc., Inc. .....No. 4: 30
Fluid and Particle Mechanics—Lapple ....No. 7: 24; No. 8: 28
Fuel Oil Manual—Schmidt, No. 12: 34
Gas Data Book—Matheson Co., Inc. .....No. 9: 28
Heat Transfer and Pressure Drop During Viscous Flow Across Unbaffled Tube Banks—Bergelin, Colburn, and Hull. No. 1: 30
Herbert H. Dow. Pioneer in Creative Chemistry — Campbell and Hatton .....No. 11: 28
Impact of Science on Society—Russell .....No. 8: 48
Industrial Chemicals — Faith, Keyes, and Clark.....No. 1: 30
Industrial Water Pollution — Weiss .....No. 12: 34
Introduction to Textile Finishing —Marsh .....No. 4: 30
Josiah Willard Gibbs—Wheeler, No. 6: 30
Liquid Extraction—Treybal. No. 8: 28
Market Research Sources—Randall and Sharpnack...No. 8: 28
Methods of Operations Research —Morse and Kimball..No. 3: 32
Oil for the World—Schackne and Drake .....No. 2: 30
Petroleum Facts and Figures—Am. Petroleum Inst...No. 10: 30
Practical Engineer Pocket Book, with technical dictionaries in German, French, and Spanish —Moore (Ed.) .....No. 6: 30
Principles of Chemical Thermodynamics—Paul .....No. 9: 28
Principles of Phase Equilibria—Wetmore and Le Roy..No. 4: 30
Review of Current Research and Directory of Member Institutions—A. S. E. E.....No. 8: 28
Sourcebook on Atomic Energy—Glasstone .....No. 3: 34
Statistical Engineering in Chemical Process Industries—Thomen .....No. 3: 32
Surface Activity — Collie and Moillet .....No. 12: 34
Technological Applications of Statistics—Tippett ....No. 4: 30
Toxicology of Uranium—Tannenbaum (Ed.) .....No. 3: 34
Ultrasonics — Vigourex..No. 9: 28
Vitamin B Complex—Robinson, No. 10: 30
Water Supply & Treatment—National Lime Assoc. ....No. 8: 50
Butadiene Catalyst, Davison to Make .....No. 11: 30

C

Cake-Filtration 497, 502
Capacitometer (see Fluidization). 199
Capryl Alcohol (see Extraction)... 186
Cast Alloy Reference Sheets, 382, 440, 494, 542, 592, 654
Catalysis: Alumina Activated with Anhydrous Hydrogen Fluoride.. 469
Catalyst, Dealkylation (see Catalysis)
Catalytic Cracking Correlations, Moving Bed Recycle 95
Reactors, Design of Fixed Bed 287
Chemical Engineer and Atomic Energy .....No. 3: 19
Chemical Engineering: Education Projects Committee (see A.I.Ch.E.)
In Small Development Organization 102
Research Problems in..No. 1: 11
Science .....No. 11: 22
Monograph Series 441, 528
Symposium Series..441, 528, 591
Chemical Exposition, No. 8: 22, No. 11: 34
Chemical Processing Equipment (see Filtration, Filters)
Chemical Reaction (see Absorption)
Chemical Spectroscopy, Lecture Available .....No. 9: 40
Cooling Medium—Gas Plant Uses Sea Water Cooling ....No. 5: 21
Committees (see A.I.Ch.E.)
Compressors, Temperature Change for Reversible Polytropic Paths.. 191
Compressors and Expanders: Work of Isentropic Compression..... 80
Construction, Chemical Plant Operations and Weather 277, 339
Continuous Systems (see Ion Exchange)
Costs, Chemical Plant 385
Council's Report (see A.I.Ch.E.)
Crystallization: Rate of Growth of Crystals in Aqueous Solutions.. 168

D

Diffusion: Column type, Stage type, 51, 63, 111, 123
Mass Separation of Gas Mixtures by 51, 111
Sweep—Gas Separation Process (see Diffusion, Mass), 63, 123
Turbulent in Fixed Beds of Packed Solids (see Vol. 46, 233, (1950) 101
Distillation, Algebraic Solution of McCabe-Thiele Diagram 265
Extractive Design and Application 555
In 2, 4, and 5.75 Inch Diameter Packed Columns.....344, 565
Research Study .....No. 11: 24
Salt Effect in Vapor-Liquid Equilibria 304
(See Transfer, Heat) 309
Ternary 555
Distilling Column (see Hydrogenation)
Driers, Roto-Louvre 508
Drying, Passage of Solids Through Rotary Kilns 508
Solvent 649
Spray, Santomerse 29
Dust Concentrations (see Elutriation)

E

E. C. P. D. Annual Report..No. 3: 31
Accredits Ch.E. Courses, No. 12: 20
Ceramic Eng. Bibl.....No. 6: 28
Guidance Manual ....No. 6: 45
Meeting in Boston ...No. 10: 28
Study of Qualification Procedures .....No. 7: 38
Electrochemical Society ...No. 8: 22
Editorials:
Case for Government Research Contracts 331
Chemical Engineering Progress 1
Conserving Technical Manpower 159
Consider the Ant 105
Maturity and Responsibility.. 383
Minimizing Personnel Obsolescence 215
Post-College Slump 543
Progress Through Separate Publication 441
Redesigning Lives 275
Standardization and Diversity 593
Time to Stop Fooling..... 49
Values of Cooperation 495
Elutriation, Fines from Fluidized Systems 39
In a Fluidized Bed 566
Engineer: A Post-graduation Five-Year Plan for .....No. 12: 18
Engineering, Improving Liaison Between Research and 161
Inst. of Canada: Officers Elected .....No. 6: 26
Manpower Commission (see Engineers Joint Council)
Profession—No. 2: 17, 107; No. 3: 19, 30; No. 4: 161; No. 5: 217, 219; No. 7: 36; No. 9: 17
Engineers Joint Council—No. 1: 26, 28, 29, 35; No. 3: 44, 159; No. 5: 31, 42; No. 6: 40; No. 7: 22, 34; No. 8: 21, 24; No. 9: 33; No. 11: 22, 24
Engineers, Registration Law..No. 7: 33
Their Background, Education and Selection 107
Meet Monthy in Peru..No. 12: 24

Esterification: Vapor-Phase Catalytic Rates 243
Ethyl Alcohol 415
Ethylene 134
Evaporator, Multiple-effect, No. 8: 38; (see Food Processing)..... 325
Exchange, Heat (see Transfer, Heat and Transfer, Mass)
Executive Caliber, Are You Of.... 217
Expanders (see Compressors)
Extraction, Cobaltous Chloride with Capryl Alcohol in a Spray Tower 186
Diffusion Rates in Extraction of Porous Solids, Single Phase—Two-Phase 405, 628
Hydrogen, Helium ..51, 111, 123
Limiting Flows in Packed Extraction Columns 423
Solids 83
Steady-State Transfer Problems—Graphical Solutions. 83
Solvent: Mixed Hydrocarbon Solvents for Fatty Acids, Their Triglycerides 347

F

Fractionation (see Distillation)
Fabric Filter Media 545
Fertilizer Plant (Nitrogenous) No. 6: 26
Filter, What Type and Why..... 502
Filters (see Pollution)
Filtration 3, 545, 550
Recent Advances in Filtration Theory 497
(See Fabric Filter Media, Pollution)
Rates 550
Resistance to 3
Fire Prevention (see Safety, Accident Prevention)
Fischer-Tropsch: Catalyst Evaluation and Middle Oil Preparation 392, 455
Flow, Continuous 46
Countercurrent 83
Heat 191
Split (see Transfer, Heat).... 211
Systems, Reaction in Series of Agitated Vessels 46
Fluid Dynamics 91
Momentum, Mass, and Heat Transfer 181
Fluid Mechanics, Conference on No. 9: 53
Fluidization 566
(See Transfer, Heat, 637)
Elutriation of Fines from Fluidized Systems 39
Fluid Catalyst Gas Mixing in Commercial Equipment ... 401
Gasification of Carbon-Metal Oxides in a Fluidized Powder Bed 251
Uniformity of Its Measurement and Use 199
Fluidized Systems, Elutriation Phenomena 39
Fluidynamic Desurger ....No. 9: 26
Fluosilicic Acid .....No. 11: 30
Food Processing, Chemical Engineering in Frozen Food Industry. 325
Edible Oil Industry 489
Meat Packing Industry, Chemical Engineering In 443
Freon 12, Refrigerants (see Transfer, Heat)
Frozen Food (see Food Processing)
Fugacities (see Liquid-Vapor Equilibria)

G

Gas Compressors (see Compressors and Expanders)
Gas-Film Efficiencies 523
Gas Separation Process (see Diffusion Sweep)
Gases, Thermal Conductivity of.. 223
P-V-T Relations of 579
Glass Industry, Chemical Engineering In 205
GR-S (see Rubber, Cold)
Graduate Education in Chemical Engineering (see A.I.Ch.E. Committees) .....No. 3: 46
Granular Beds 370

H

Heat Transfer (see Transfer, Heat)
Hydrocarbons, Aromatic (see Catalysis) 469
(C_4)—Furfural Mixtures 151
(See Phase Equilibria) 419
Hydrogenation (see Fischer Tropsch) Reaction in Rectification Column 283
Hypersorption Design, Modern Advancements 585

I

Improving Liaison Between Research and Engineering 161
Indoor Construction.277, 339, 341, 385
Industrial Hydraulics, Conference No. 8: 42
Industry - Sponsored School (see also A.I.Ch.E. Committees), No. 10: 48
Teaches the Teacher (see Industry Sponsored School), No. 9: 48
Technical Training in ..No. 9: 17
Institution of Chemical Engineers 1949 Transactions, No. 5: 37; No. 9: 40; No. 10: 24, 50
Ion Exchange, Continuous Countercurrent 529
Isomerization, Reactions in Rectification Column 283

J

Jet Pumps: Free Jets of Air Mixing with Air 175
Momentum, Mass, and Heat Transfer 181

K

Kinetics 528
(Abstr. artice in "C.E.P." Monograph Series No. 1)
(See Esterification) 243
Catalytic Formation of Phosgene 473
Principles of Reactor Design.. 333

L

Leaching Problems 83
Lecture Institute (see A.I.Ch.E.)
Letters to the Editor
Brownell, L. E.—Pressure Drop Through Porous Media 315
Clegg, J. W.—Notation for Large and Small Numbers 38
Douglas, J. A.—Maturity and Responsibility 584
Gerald, C. F.—Measuring Fluidization Uniformity 483
Johnstone, R. Edgeworth—Notation for Large and Small Numbers 110
Leva, Max — Pressure Drop Through Porous Media..... 314
Miller, B.—Liquid Metal Heat-Transfer Coefficients 269
Morse, Rollin D. — Measuring Fluidization Uniformity 483
Newman, A. B.—Reactors in Series 274
Rayfiel, R. D.—Multicomponent Rectification 608
Rorschach, R. L.—A Young Man Looks At His Profession. No. 6: 52
Rushton, J. H.—Modified Reynolds Numbers 381
Wilson, Ernest D.—Notation for Large and Small Numbers... 242
Liquid Film (see Absorption)
Liquid-Film Efficiency 523
Liquid-Vapor Equilibria (see Phase Equilibria) 419, 449, 571, 609
Local Sections (see A.I.Ch.E.)

M

Marginal Notes (see Book Reviews)
Mass Transfer (see Transfer, Mass)
Meat (see Food Processing)
Medals (see Awards)
Perkin ....No. 1: 46; No. 11: 21
Howard Coonley....No. 11: 22
S.C.I. .....No. 12: 32
Meetings (see A.I.Ch.E.)
Metal Oxides (see Fluidization)
Methyl Ethyl Ketone 649
Methyl Ethyl Ketone-Naphtha.... 11
Mixing, Continuous 363
Practical Techniques for Viscous Materials 397
Use of Pilot Plant Mixing Data. 485
Monograph Series 441, 528, No. 12: 17

N

Nat. Council State Boards of Eng. Examiners (see A.I.Ch.E.)
Production Authority, No. 6: 54; No. 8: 51

O

Oil, Edible (see Food Processing)
Opinion and Comment (see Editorials)

Pages by months: January, 1-48; February, 49-104; March, 105-158; April, 159-214; May, 215-274; June, 275-330; July, 331-382; August, 383-440; September, 441-494; October, 495-542; November, 543-592; December, 593-654

Outdoor Construction, 277, 339, 341, 385
Oxygen-Carrier (see Fluidization)

P
P-V-T Relations of Gases 579
Packings: (see Distillation)
Pan American Union of Association of Engineers (UPADI), No. 5: 42; No. 10: 26
Particles, Elutriation of (see 566)
Orientation 91
Stacked Spheres 91
Permeability (see Filtration)
Pharmaceutical Manufacture, Scheibel Extractors in .....No. 7: 20
Phase Equilibria: An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures, 419, 449, 571, 609
Phosgene 473
Plant Maintenance Conference, No. 11: 22
Pollution Abatement and Industrial Water Management 376
Air Pollution at Low Altitudes. 436
Performance of Industrial Aerosol Filters 462
Pollution Air: Control of in Chemical Industry 481
New Publication .....No. 9: 36
Sewage Treatment Plant, No. 8: 24
Polystyrene 432
Pressure Drop Through Stacked Spheres—Effect of Orientation. 91
Process, Batch (see Rubber, Cold)
Continuous (see Rubber, Cold)
Variables (see Catalytic Cracking Correlations; also Solvent Extraction)
Processing Plants (see Hypersorption)
Professional Legislation Committee (see A.I.Ch.E.)
Product Distribution (see Catalytic Cracking Correlations)
Publication Committee (see A.I.Ch.E.)

R
Reaction Kinetics in Chemical Engineering 528
(Abstr. article in "C.E.P." Monograph Series No. 1
Reaction Rates (see Kinetics)
Reactors (see Kinetics)
Continuous Flow Stirred Tank. 363
Reforming Process; Atlantic Develops New .....No. 3: 20
Research 161
Rheology: Pressure Drop of Fluid Polystyrene in Conduits..... 432
Rotary Kilns (see Drying)
Rubber, Cold: Design of Continuous Process 270

S
Safety in Chemical Plant Operations 595
Management Viewpoints on Plant Safety 598
Outdoor Construction (see Construction)
A.S.A. Safety Standards Asked .....No. 3: 23
M.C.A. Data Sheet....No. 6: 52
M.C.A. Safety Awards. No. 9: 30
Record by Chemical Plants, No. 7: 32
Salary, How Determined 219
Salts, Inorganic (see Distillation)
Secretary's Report (see A.I.Ch.E.)
Separation, Isotope (see Diffusion, Mass) 51, 111
(Also see Diffusion, Sweep, 123)
Sewage Treatment .....No. 8: 24
Solids Extraction Problems 83
Solution—Clarification 497, 502
Solvent Extraction 11, 649
Sonic Energy, Applications of in Process Industries 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Application of to Commercial Aerosol Collection Problems 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Sonic (and Ultrasonic) Energy; Basic Principles of Application.. 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Sonic (Ultrasonic) Energy, Physical and Economic Limitations in Application of to Industrial Processing 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Spinning Disk Atomizers (see Atomizers)
Spray Drying of Santomerse..... 29
Sulfur .....No. 10: 32
Extraction Plant in West Texas, No. 7: 33
Freeport to Develop New Deposit .....No. 9: 34
Nitric as Sulfuric Substitute, No. 9: 47
Recovery Plant .....No. 11: 24
Shortage Due to Foreign Lag, No. 7: 28
Three Million More Tons, .. No. 10: 32
Sulfur Dioxide (see Absorption)
Student Chapters (see A.I.Ch.E.)
Symposium Series.....441, 528, 591

T
Technical Training in Industry, No. 9: 17
Temperature, Change for Reversible Polytropic Paths 191
Thermodynamics: Thermodynamic Properties of Ethyl Alcohol 415
Titanium .....No. 11: 23
Research Announced ..No. 7: 34
Transfer, Countercurrent 91
Transfer Heat: Between a Vertical Tube and Fluidized Air-Solid Mixture 637
Transfer, Heat: Boiling Coefficients of 151
By Direct Contact Between Liquid and Vapor 309
Design of Fixed-Bed Catalytic Reactors 287
Effect of Vapor Agitation on Boiling Coefficients 317
Effective Thermal Conductivity of Granular Solids Through Which Gases Are Flowing. 295
For Fixed and Fluidized Beds. 19
Liquid Metal Heat Transfer Coefficients 75
Processing Viscous Materials. 354
Temperature Gradients in Gas Stream Flowing Through Fixed Granular Beds 141, 507
True Temperature Difference in Split Flow 211
(See also Gases) 223
Transfer, Mass; For Fixed and Fluidized Beds 19
Laminar Flow of Gases Through Granular Beds... 370
Rates on Bubble Plates..523, 621
• (See Absorption)
Transfer Systems, Countercurrent.. 83
Treasurer's Report (see A.I.Ch.E.)
T. V. A. .....No. 10: 48

U
Ultrasonic Power, Kilowatts of, for Industry 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Ultrasonics 528, 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
Colloidal Effects of 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
In Study of Matter 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Material Testing and Gaging with 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Physico-Chemical Effects of.. 528
(Abstr. article in "C.E.P." Symposium Series No. 1)
Ultrasound, Mechanism of Biological Effects Produced By 591
(Abstr. article in "C.E.P." Symposium Series No. 1)
United Nations, UNESCO No. 5: 30; No. 12: 32

V
Vapor-Quenching Equipment..... 309
Viscous Materials (see Transfer, Heat; Mixing)

W
Waste Disposal (see Pollution); (also see No. 4: 33)
Water Management 376
Wax Molding Process .....No. 9: 30
Weather (see Construction)

Y
Yarns (see Fabric Filter Media)
Young Engineer Looks at His Profession .....No. 2: 17

NEWLY ELECTED A.I.Ch.E. OFFICERS

W. I. BURT
President

A record number of votes by the members of the A.I.Ch.E. in the recent annual mail balloting has elected for 1952 W. I. Burt, vice-president, manufacturing, the B. F. Goodrich Chemical Co., President, and W. T. Nichols, director, general engineering department, Monsanto Chemical Co., Vice-President. The vice-presidential office was the top executive position in which there was a contest, Nichols winning over C. G. Kirkbride, vice-president and director, Houdry Process Corp., and D. B. Keyes, consultant and director, Heyden Chemical Corp. But Burt was unopposed for office as were C. R. DeLong, vice-president, North American Solvay Inc., and the Solvay American Corp., re-elected Treasurer and S. L. Tyler, re-elected Secretary.

The contest for Directors in which 14 candidates were up for election to five open positions resulted in the election for a one-year term of W. T. Dixon, manager, design division, engineering and construction department, Atlantic Refining Co. Four other Directors elected for a three-year term were: J. H. Rushton, professor of chemical engineering and director of department, Illinois Institute of Technology; Philip H. Groggins, chief, agricultural chemicals section, chemical division, National Production Authority; J. C. Elgin, professor of chemical engineering, chairman of department and associate dean of the engineering school, Princeton University, and Arthur K. Doolittle, assistant director of research, Carbide and Carbon Chemicals Co.

The election of a director for one year became necessary when Walter G. Whitman, elected a Director in 1950 for a three-year term, resigned from Council. Another candidate for that position was A. W. Low, division engineer, Monsanto Chemical Co.

Out of a total possible vote of 4070 active members, 2392 ballots were cast according to a report of the Tellers Committee headed by W. D. Kohlins of the Buflovak Equipment division of Blaw-Knox Co.

W. T. NICHOLS
Vice-President

J. H. RUSHTON
Director

P. H. GROGGINS
Director

J. C. ELGIN
Director

A. K. DOOLITTLE
Director

W. T. DIXON
Director

A. I. Ch. E. AWARD WINNERS—1951

MAJOR professional awards in chemical engineering for technical literature, the William H. Walker Award and the Junior Award of the American Institute of Chemical Engineers, were won this year respectively by Richard H. Wilhelm, professor of chemical engineering at Princeton University, and Charles R. Wilke, associate professor of chemical engineering at the University of California. The presentations were made at the Awards banquet held at the 44th Annual Meeting of the Institute at Chalfonte-Haddon Hall, Atlantic City, N. J., December 4th.

At the same time, the Professional Progress Award in Chemical Engineering was given to Chalmer G. Kirkbride, as announced in the October issue of Chemical Engineering Progress, page 24. The Student Contest winners were also honored at the banquet.

Dr. Thomas H. Chilton, President of the A.I.Ch.E., and technical director of the development engineering division of E. I. Du Pont De Nemours & Co., made the formal presentations.

In winning the 16th Walker Award, Professor Wilhelm makes it the third in a row for the teaching profession. He was chosen on the basis of "his excellent publication record over the years and for his contributions to Chemical Engineering Progress." The award winners this year were chosen by the Awards Committee headed by Dr. Allan P. Colburn, Provost of the University of Delaware.

A native of New York City, Professor Wilhelm received his B.S. degree in 1931 from the Columbia School of Engineering, his Ch.E. in 1932, and in 1935 he received his Ph.D. degree in chemical engineering from the Columbia Graduate School. Prior to completing his graduate work, he went to Princeton in 1934 as an instructor in chemical engineering, rising to assistant professor in 1937, associate professor in 1943, and from 1946 to date, full professor.

Professor Wilhelm was director of the Princeton Bicentennial Conference (1946) on "Engineering and Human Affairs," and is a licensed professional engineer in the State of New Jersey. He is at present a member of the management committee of Chemical Sciences Laboratory of Princeton's newly founded Forrestal Research Center, and is a consultant to the Research and Development Board of the Department of Defense, and to various chemical companies. In 1949 he was instrumental in organizing a program of studies at Princeton combining elements of chemical engineering and biology.

RICHARD H. WILHELM

The Junior Award given for "outstanding contributions to the literature in chemical engineering by Junior members of the Institute," was given to Professor Wilke for his articles on "Estimation of Liquid Diffusion Coefficients," "Diffusional Properties of Multicomponent Gases," and "Limiting Flows in Packed Extraction Columns," all published in Chemical Engineering Progress.

Professor Wilke, a native of Ohio, received his B.S. degree in chemical engineering from the University of Dayton in 1940; his M.S. from State College of Washington (1942); and received his Ph.D. degree in 1944 at the University of Wisconsin. Upon completion of his graduate work, he went with the Union Oil Co. of California for one year. In 1945 he went to State College of Washington as an instructor, and in 1946 to the University of California also as an instructor, rising to assistant professor in 1947 and associate professor in 1951.

CHARLES R. WILKE

One of his many present duties is the direction of research, including projects sponsored by the Atomic Energy Commission and the office of Naval Research. His research fields include the theory of mass transfer and diffusion, performance of absorption, distillation and extraction equipment, gas viscosity, and concentration polarization in electrolysis.

The Third Institute Lecture was delivered this year by Thomas Bradford Drew, head of the department of chemical engineering, Columbia University. His subject, "Diffusion, What We Know and What We Don't," will form the basis of a Chemical Engineering Progress Monograph Series, and will be published next year. The Institute Lecture was announced in the October issue along with the Professional Progress Award winner.

Student Contest Winners

The A. McLaren White Award for the best solution to a problem in chemical engineering selected by the Committee on Student Chapters, was won this year by Karl W. Rausch, Jr., a chemical engineering graduate of Yale University, June, 1951.

The problem selected by the committee this year concerned the design of a plant for the manufacture of a dextrose containing syrup from cornstarch and intentionally involved the concept of economic balance encountered in the process industries. The students were asked to determine the operating conditions giving the minimum manufacturing cost, and to specify the basic engineering factors required for the mechanical design of the plant.

The special subcommittee of the Committee on Student Chapters which prepared the problem, was headed by W. L. Faith, and included John E. Dlouhy and Robert H. Rogge, all of Corn Products Refining Co.

Mr. Rausch is at present employed by the General Electric Co., in the process development section of the chemical

(*Continued on page 36*)

A Postgraduation Five-Year Plan for the Engineer

RALPH L. WENTWORTH

Massachusetts Institute of Technology, Cambridge, Massachusetts

AN electron microscope expert at the R.C.A. laboratories, James Hillier has recently estimated that the 40,000 microphotographs taken in his laboratory over the last nine years picture just about one square millimeter of surface. Hillier obviously has a long way to go before running out of new worlds to conquer, and it might be thought that the planning of his future research would be a simple matter: just snap the shutter as the samples move across the stage of the microscope. But the job is not as easy as that. The very property of the electron microscope which makes it so valuable, the fine-grained study of matter which it makes possible, limits the area which can be studied with it. To make the most effective use of the instrument its schedule of use must be fitted into a research plan. The field of study must be carefully chosen, the technique of operating the microscope must be adapted to the samples, and the results carefully interpreted.

Principles like these which guide successful scientific research are familiar to engineers. An engineer has been trained to apply orderly methods of procedure to his job; he knows that handling the electron microscope and the giant Palomar telescope is different only in objective. It is less well appreciated that the technique applies equally well to directing ordinary mortal affairs; business, politics, or aiming a career. What is suggested is that an engineer, contemplating his course of action after graduation, should use those methods of procedure with which he is most familiar from his everyday work.

Operations Research

If a name for this practice is desirable, it might be identified with the new and fascinating discipline of operations research. Operations research is applied science in making policy decisions. In its simplest application it results in economical and effective action on the basis of obvious data; in extended form it allows decisions based on analysis of all the probabilities, statistical data, and fundamental governing principles involved in a problem. Impressive contributions to the problems of submarine hunting and bombing accuracy in World War II were made through the use of operations research. Development since then indicates promise in the fields of business administration and economics.

The comparison of career-planning with operations research is suggested because operations research stresses the fact that planning should be flexible and based on every fact that has bearing on the problem. This is in good agreement with the American philosophy that rejects regimentation and depends for effectiveness on a dynamic system; always moving; always subject to questioning. In getting a postgraduation plan under way there is needed, not a timetable, but a selection of the goal and procedure according to the best methods.

Engineering and Living

What should be the engineer's goal, then? The trite answer is, of course, "success." As a nebulous expression of his final happy state this is well enough, but it should be remembered that here the engineer is being limited to five years. And a goal for five years can be stated in simpler terms. Just as college training provides the foundation for becoming a member of the engineering profession, the five-year period after graduation is a good measure, more or less, of the time needed to acquire technical competence in the profession. At the same time these years provide the graduate his first opportunity to deal with society strictly on his own, free from the earlier shelter of parents and schools. Learning the ropes in these two fields—the mechanics of his profession and the art of living—is the modest goal set for the first five years. This program probably seems a bit dull. But a quicker profit on the investment laid out in becoming an engineer is not the general rule, either with planning or disregarding it; the goal stated here can be regarded as laying the basis for insuring success in the long run. For example, a recent study disclosed that the average earning power of a group of chemists and chemical engineers now in topnotch positions had just about doubled five years after graduation. If we take this as one indication of achievement, the scientist in these fields cannot expect to retire with wealth and fame shortly after graduation.

Ralph L. Wentworth has been affiliated with M.I.T. since 1944 on research projects in the department of chemical engineering, chiefly on problems concerning hydrogen peroxide for the U. S. Navy. He is now engaged in the preparation of a monograph on hydrogen peroxide with W. C. Schumb and C. N. Satterfield. A native of Missouri, Mr. Wentworth attended the University of Missouri, received a B.S. in chemistry from Harvard University (1944) and an M.S. in chemical engineering from M.I.T. (1948). He is an active member in the Ichthyologists (Boston Section, A.I.Ch.E.). In the accompanying article, based on the first award paper in the 1951 Engineering Societies of New England Essay Contest, Mr. Wentworth describes Operations Research, its analogy to career-planning, and stresses the importance of the engineer's foreknowledge of his own aptitudes, abilities, and skills in his preparation for the engineering profession. This contest is conducted annually—open to members under 30 years old of all the individual engineering groups which are joined in the E.S.N.E. The 1950 contest was won by J. B. Weaver whose paper was run in February, 1951, "C.E.P."

The slow and steady course leading up to real success as an engineer has an exact parallel in the development of a new product. Contrary to popular belief, the invention of something new and useful does not automatically bring down a shower of money and jobs. Invention itself is generally a costly process these days and development over a period of years is required before the new product assumes importance in the economy. Acceptance of this measured approach may be a little chilling to the eager, but the fact is that the get-rich-quick attitude does not bear fruit. For want of a better tag let us call the present method the get-effective-quick approach. The odds are stacked in favor of it.

Adjusting the Man and the Job

With the aims of a postgraduation plan established it is necessary to look into the procedure for getting results. On the professional side the first consideration is fitting the job and the man together. It is likely that an engineer ready to look into the probable outcome of his career already has a job. But consideration of the job for the man can still be important for the engineer already at work. If he has not done it already, the engineer should set about appraising his position. Does he get results? Can he see the paths available for advancement? Is the company policy agreeable? Are his abilities suited to the job? This last question is at the real heart of the matter, for matching ability and aptitude to the job is essential. Unfortunately the matching of job and ability does not receive the attention it should.

Ideally, employment should take some course such as this: A group of employers presents the needs of their business along with a complete description of the surroundings in which they are carried out; the graduates, on the other hand, present the training, the aptitudes, and the personality which each possesses. All of this would take place with large-scale samples. Then providence in the guise of a punched-card machine could do a good job of securing satisfaction for both sides. Why does a gap exist between this ideal, if somewhat impractical, scheme and actual practice? Well, largely because of the inadequacy of the job-seeker, it would seem. Employers these days generally do a good job of presenting the facts, from the illustrated brochures describing company aims to at-the-plant interviews and visits. But the graduate, although he knows what specific training he posssesses and knows fairly well where and what the jobs are, he does not know what innate properties, peculiar to himself, he has to offer. Part of this is the fault of the schools, which must concentrate heavily on delivering technical training, but even at the best the graduate cannot expect to have his course charted for him. Gaining knowledge of himself is part of the process of maturing, and the graduate should see to it that he makes an assessment of what engineering has to offer and what his abilities are.

The Personal Equation

If the suggested scientific approach is applied in trying to evaluate ability, it will be found that much is known today about what constitutes mental and physical ability. It appears that the simple factor, such as the I. Q., is inadequate in describing ability. For there is a number of primary abilities, and one is born with them or acquires them at an early age. Such things as the ability to visualize objects in space, facility in doing simple arithmetical tasks, verbal comprehension, fluency in speaking, ability to memorize, and speed of perception differ widely among individuals. Qualities like these are just the ones that, when developed, determine whether the engineer may expect to become successful in the various phases of engineering such as research, development, management, and production. A graduate who has taken account of himself will not find himself in design work when he is cut out for technical sales. But before relaxing efforts in certain directions after drawing up an ability profile, it is necessary to remember that performance on the basis of these abilities is largely determined by opportunities and motivation. This means that an engineer must know what engineering takes including energy and effort.

The demand for graduates of cooperative or on-the-job training programs furnishes a clue to what the engineer needs to acquire in addition to fundamental technical background. The graduates of these practice school plans have developed an alertness to practical problems that immediately makes them valuable on the job. Knowing how and where to buy steel stock can be of equal value with knowing how to determine its physical properties. But strangely enough, this kind of information, which can be picked up without much more effort than keeping the eye and ear open, is generally neglected. The common phrase to describe this property is "well rounded." On the basis of a scientific approach to implementing a career it means overlooking no information that will serve, when the opportunity arises, to further both the career and the profession.

This matter of serving the profession brings the second consideration of the postgraduation aims, the human side of affairs, directly into view. Currently there is an argument on the question whether engineering is really a profession. The truth seems to be that engineering can be a profession, but only so long as its activities are conducted with full regard to their impact on society. If an engineer conducts himself on the professional level, he benefits not only others but himself. The benefit comes through personal satisfaction, which is a necessity in the pursuit of any career. John Donne put it, "No man is an island," many years before the psychologists started to explain human needs. In the postgraduation years the engineer has the chance to develop the habit of orienting his work so that this satisfaction through social benefit always comes as a part of it.

The Social Balance

To acquire this attitude in the beginning probably takes conscious effort and attention away from the technical problems of engineering. At the drawing board, in the shop, facing the customer, in all these places there should be an attempt to make a social balance as well as an economic balance. When a little more authority comes the way of an engineer there should be a periodic evaluation of personal relationships on the job. This takes development of a lateral or downward viewpoint, because attention is often focused on the leaders ahead and doing a job with no more thought than to satisfy their demands is to overlook an important part of it.

It is necessary to pay attention to activities away from the laboratory or plant; career-building involves the whole day, not just the job. In these days of easy communication the methods of procedure are easily available. All have heard of the value of hobbies and the contribution the engineer can make through community service. One word of caution only: A little moderation is sometimes necessary in personal pursuits. From the advice of some, one would be expected to run for political office, manage the Boy Scouts, acquire Olympic skill in tennis and swimming, in fact, engage in dozens of activities. This is fine if one wishes to be jack of all trades, but it is probably not consistent with outstanding accomplishment. For a look at the biographies of a few men of real achievement, and in the engineering profession, too, will show that their successes were always the result of a lifetime of preparation which seems to have been peculiarly appropriate to the goal that was achieved.

The real contribution of the integration of personal accomplishment in the sphere of human relationships into an engineering career will be seen whenever a measure is taken of the success of the career. Those credits that come under the heading of character and ethics, the qualities which distinguish between the job merely done and the job that excites professional admiration, are due largely to the degree to which the engineer has recognized his obligations as a member of a profession.

This outline of a procedure for a postgraduation plan can be expanded in detail to book size. It can be tailored to the unique requirements of each individual. But even as a book, it could not do more than suggest that becoming an engineer requires more than getting a degree, that learning to be a professional man must be a part of the task of the after-graduation years. The application of the information is the individual engineer's job. Perhaps we can put it in most usable form by recommending the phrase: "Cultivate alertness."

(The End)

A novel design for protection of life and equipment is represented by the Wm. S. Merrell Co.'s new organic research laboratory, which began full-scale experimental production of medicinals during the latter part of November. The upper photograph shows the concrete-block walls between the two wings and the quarter-inch asbestos-like outer walls. Should an explosion occur, the loosely fastened outer panels would be blown away from the solid inner walls by the force of the blast, thus allowing the gases to escape outward. The six exhaust fans connect with individual drug production booths (lower photograph) to rid the interior of noxious gases.

Twelve production booths are divided between the two wings so that, should an explosion occur in one wing, production could continue in the other. Each booth is 5 ft. wide and 5 ft. deep, and is equipped with every service needed for efficient drug preparation: steam, compressed air, vacuum, distilled water and electricity.

Special air-handling equipment seals the entrance to the booth with a blanket of filtered, temperature-controlled air, and circulates more than 1,200,000 cu. ft., or 42 tons of air every hour (enough to ventilate 100 five-room homes) through the drug production area, sweeping away all traces of obnoxious or explosive vapors and preventing cross-contamination of chemicals. In addition, each booth has its own 8-in. flexible hose connected to the exhaust manifold, thereby providing additional localized suction for special applications or particularly hazardous operation.

The special formula cement floors will not spark if a worker drops a piece of metal or wears shoes with steel nails in the soles. All electric wires and fixtures (telephones, clocks, temperature controls, etc.) are enclosed in explosion-proof steel or half-inch thick glass, while nonsparking phosphorous bronze has been used in the moving parts of the air-handling equipment. Instantaneous emergency showers and an eye-wash fountain have been installed just outside the administrative area near the doors to the production wings. The laboratory and main building, which houses medical drug formulas, raw materials and finished products, and service machinery, are isolated from each other by a concrete wall and heavy steel fire doors.

Among the drugs now being produced in the new laboratory are bentyl hydrochloride, for gastro-intestinal therapy; ceepryn chloride, used in Cepacol, an alkaline, antibacterial solution for oral hygiene; and the antihistamine, decapryn. To ensure clear visual inspection during the manufacturing processes, scientists work with glass, rather than with the more conventional steel equipment.

E.C.P.D. ACCREDITS FOUR Ch.E COURSES

Engineers' Council for Professional Development accredited four additional chemical engineering courses at its recent meeting in Boston according to information made available to the A.I.Ch.E. The new schools are: Villanova College, State College of Washington, University of North Dakota, and Kansas State College.

The action was taken by E.C.P.D. upon receiving the recommendation of the Council of A.I.Ch.E. that these schools be accredited. Council in turn had acted upon a report of the A.I.Ch.E. Committee in Chemical Engineering Education and Accrediting, headed by G. G. Brown, dean of engineering, University of Michigan, Ann Arbor.

BLAST FURNACES USE PRESSURE OPERATION

In a report on the status of the new method of operating iron blast furnaces under pressure, B. S. Old, vice-president of Arthur D. Little, Inc., the Cambridge (Mass.) engineering firm, revealed that all six of the large blast furnaces now under construction in the United States will operate under pressure and that five old furnaces are being converted to pressure, in addition to eight now operating in the United States and one in England. He estimated that, on the basis of experience with furnaces now operating, these furnaces altogether would produce at least 1,000,000 tons more pig iron each year than if operated conventionally.

In operating a furnace under pressure the exit-gas system is throttled so that pressure at the top of the furnace builds up; pressures up to about 12 lb. above normal atmospheric pressure are now used. With the system throttled down, the air blown in the bottom of the furnace moves through more slowly, so that it is possible to blow a greater weight of the compressed air through without blowing valuable ore out of the furnace. The availability of more air permits the burning of more coke per day and thus the smelting of more iron.

The first pressure furnace started regular operation in 1946 on the Cleveland (Ohio) No. 5 furnace of Republic Steel Corp. Republic Steel recently announced that this furnace had set a company record for output, with 48,005 tons of iron produced in September, 1951. The average daily output was 1600 tons, compared with 1400 expected under conventional operation. Republic has converted 45% of its total blast furnace capacity to pressure operation.

BRAZIL TO BUILD H_2SO_4 PLANT

Chemical Construction Corp. will build for the Brazil Export Co., a 60-ton contact sulfuric acid plant that will utilize "coal brasses," a form of pyrite, as raw material. The plant will be erected for the SA Reunidas F Materazzo, a South American company noted for the production of synthetic yarn.

This will be the third plant supplied by Chemico and installed in the same city, Sao Paulo. Coal brasses contains 40% sulfur and 4% to 10% carbon.

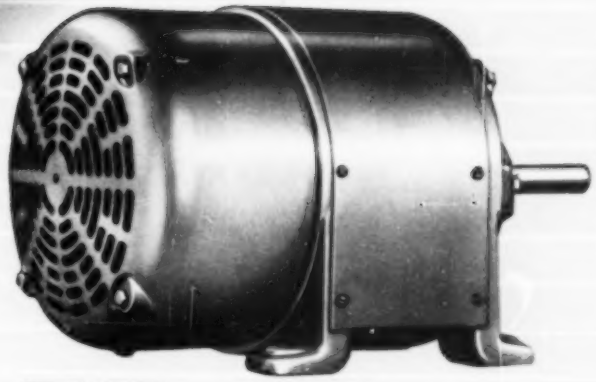
CHEMICALS IN FOODS CONFERENCE IN JANUARY

The Manufacturing Chemists' Association will sponsor an Inter-Industry Conference on chemicals in foods at the Hotel Statler, New York, Jan. 15, 1952.

(*More News on page 24*)

CERTIFIED

SAFE



TOTALLY-ENCLOSED

AND EXPLOSION-PROOF U.S. MOTORS

100% Safe... U. S. TOTALLY-ENCLOSED MOTORS

Without equal for dependability, this advanced line of motors insures safest power and longest life. The vital elements are given utmost protection against external hazards. The explosion-proof types are certified safe by Underwriters' Laboratories, Inc.

NORMALIZED CASTINGS

All castings normalized to remove internal stresses and maintain original accuracy of bearing settings and air-gap between rotor and stator, insuring for longer bearing life.

HI-DRAFT VENTILATION

Ventilating fan is of non-sparking material for explosion-proof motors. Designed with split hub, permitting quick removal. Tight in operation. Multi-bladed for quietness.

LUBRIFLUSH BEARINGS

Self-lubricated for normal life—and with the extra advantage of Lubriflush, permitting relubrication when desired without disturbing the bearings. Fresh lubricant is injected; old grease is purged.

ASBESTOS-PROTECTED WINDINGS

Asbestos-protected windings withstand high temperatures and guard against carbonization. Each wire is insulated and isolated with asbestos, to protect against burn-outs & increase motor life.

SPLIT HUB FAN

The propulsion fan forces an air blast against lamination edges, dissipating the heat as fast as it generates—keeping the motor continuously cool. The air is drawn in through end grill.

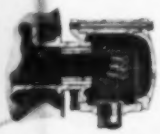
REMOVABLE COVER

The cover plate can be quickly removed by loosening screws for inspection and to eliminate deposits of dust, dirt, lint, oil and all other accumulations.

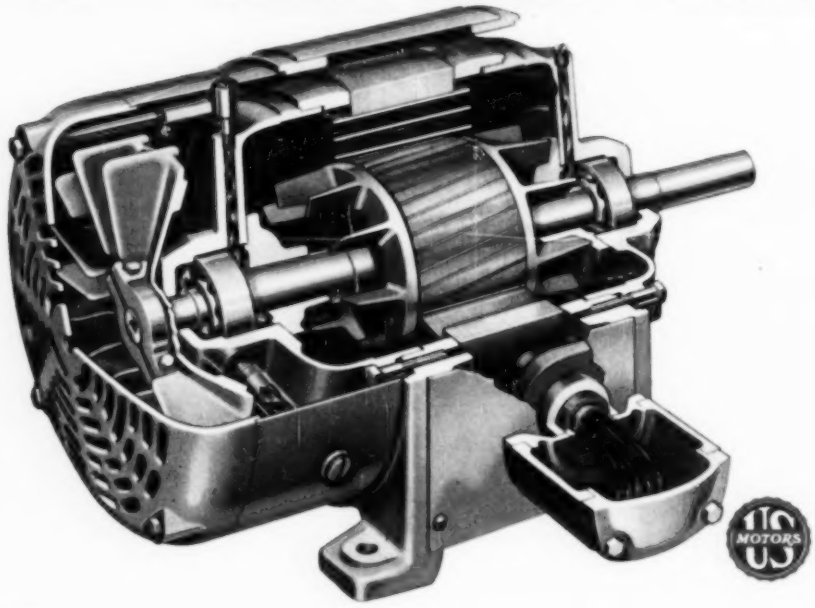
CENTRICAST ROTOR

Centrifugally cast from molten aluminum into a solid, indestructible structure, free of defects.

SEALED TERMINAL



Extra large chamber is sealed with special compound, very high in dielectric strength and with a high melting point.



SMOOTH GRILLE

For protection of the fan and to prevent entrance of debris, an oval grille is provided. Smoothly contoured.

CERTIFIED SAFE FOR HAZARDOUS SERVICES

U. S. Totally-Enclosed Motors carry the official Underwriters' label for explosion-proof services in Class I, Group D, for highly inflammable gases and volatile liquids, and Class II, Groups F and G for combustible dusts. These motors are also available for non-explosion-proof services such as chemicals, dust and moisture, without label, and with or without fan —Horizontal, Vertical and Varidrive types. New Bulletin gives full details.

U.S. ELECTRICAL MOTORS Inc.

PACIFIC PLANT: Los Angeles 54, Calif. (P.O. Box 2058) ATLANTIC PLANT: Milford, Conn.
Atlanta 3, Ga., Bakersfield, Calif., Boston 16, Mass., Chicago 8, Ill., Cincinnati 16, Ohio, Cleveland 14, Ohio, Dallas 9, Texas, Detroit 2, Mich., Fresno 1, Calif., Houston 4, Texas, Indianapolis 4, Ind., Milwaukee 2, Wisc., Minneapolis 2, Minn., New York City 6, N. Y., Philadelphia 2, Pa., Pittsburgh 2, Pa., San Francisco 7, Calif., Seattle 4, Wash.
Sales and Service offices in all principal cities

MAIL COUPON FOR DESCRIPTIVE BULLETIN

U. S. Electrical Motors Inc.
Box 2058, Los Angeles 54, Calif.
or Milford, Conn.

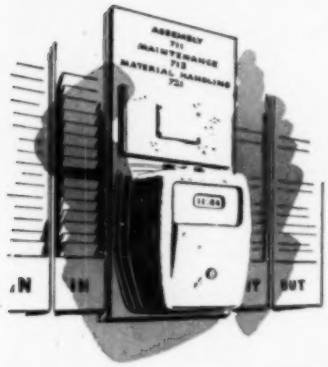
Send your new Bulletin illustrating and describing U. S. Totally-Enclosed Motors. ☐ Also General Bulletin of all U. S. Motors. ☐

NAME _____

COMPANY _____

ADDRESS _____

CITY _____ ZONE _____ STATE _____



A BOILER THAT PUNCHES THE TIME CLOCK

Yes — a Cleaver-Brooks Boiler "Punches In" to meet a heavy steam demand — "Punches Out" during low load periods.

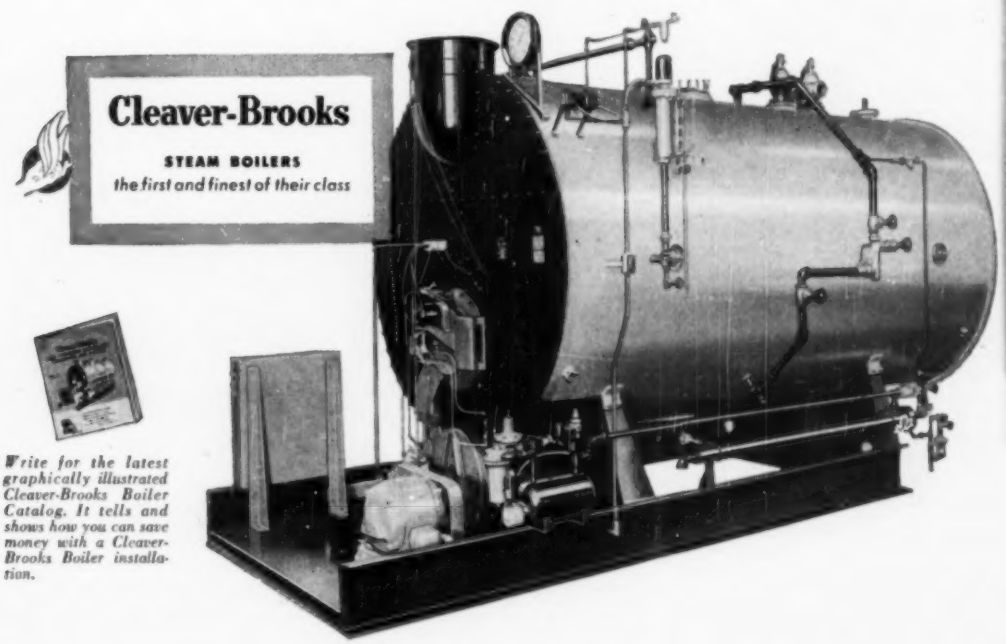
Steam costs can eat deeply into profits when steam loads fluctuate — or are intermittent. With a Cleaver-Brooks boiler you are equipped for heavy or light . . . steady or variable loads, operating at full 80 per cent efficiency over the entire working range of the boiler.

You are assured of fuel economy through high heat transfer. *All* Cleaver-Brooks boilers are of the four pass design and the maximum useable heat is absorbed in these four passes before the combustion gases leave the boiler.

Remember the name Cleaver-Brooks if you are considering a change in your present boiler plant. Think about flexibility and get the complete facts about Cleaver-Brooks Self-Contained Boilers — standard models in 15 to 500 HP, 15 to 250 psi, oil, gas, combination oil and gas fired — 80 per cent efficiency.

CLEAVER-BROOKS COMPANY
285-M E. KEEFE AVE., MILWAUKEE 12, WIS.

Builders of Equipment for the Generation and Utilization of Heat • Steam Boilers • Oil and Bitumen Tank Car Heaters • Distillation Equipment Oil and Gas-Fired Conversion Burners



Write for the latest graphically illustrated Cleaver-Brooks Boiler Catalog. It tells and shows how you can save money with a Cleaver-Brooks Boiler installation.

—Courtesy Industrial Mineral Wool Institutes

At the Glenwood gas plant of the Long Island Lighting Co., rooftop fan housings enclose induced-draft fans which draw waste gases, at temperatures from 600° F. to 700° F., from boilers through exhaust ducts to the surrounding air. To protect maintenance men, the hot fan housings are covered with mineral wool blanket insulation to about 5 ft. above roof level. The 2-in. thick mineral wool blankets are secured to the sheet-metal fan housings by welded wires approximately 3-in. long. With wire netting on the inside the blankets are impaled on the wires and the ends of the wires are bent over into the metal lath covering the outside of the insulation.

(*News continued from page 20*)

ENGINEERS TO MEET MONTHLY IN PERU

A monthly luncheon meeting has been organized in Lima, Peru, for members of all International Engineering Societies. These meetings are held every third Wednesday of the month (except holidays) at 12:30 P.M. in the Golden Room of the Hotel Bolivar. All visiting members of such societies are welcome to attend. In case of a holiday, the meeting is automatically postponed until the fourth Wednesday of the month.

C. W. Westphal, technical representative for The Dorr Co., and a member of A.I.Ch.E., is on the Program Committee for the selection of speakers. At the Sept. 19 meeting C. W. Westphal acted as chairman. Robert P. Koenig, president of Cerro de Pasco Corp., talked on "Recent Zinc Developments at Cerro de Pasco."

FELLOWSHIP AT MELLON

Establishment at the Mellon Institute Pittsburgh, Pa., of a research fellowship by the Hanley Co., was recently announced by E. R. Weidlein, president, Mellon Institute. The Hanley Co., with home offices in New York, and plants at Summerville, Pa., and Bradford, Pa., manufactures face and glazed brick, and shale floor, structural facing and wall tile. The fellowship has for its purpose fundamental research and development work in the technology of structural clay products. The program is of long-range character, to be based upon far-reaching studies of the physical and chemical properties of the raw materials and the manner in which these properties contribute to those of the finished products.

N. H. Barbre has been appointed to the incumbency of this fellowship. He was formerly associated with the Quartermaster Research and Development Laboratories in Philadelphia, where he served as physicist and unit head.

PATENTS RELEASED FOR PUBLIC USE BY A.E.C.

Descriptions of 25 patents owned by the U. S. Government and held by the Atomic Energy Commission have been transmitted to the U. S. Patent Office for registry and listing in the official register of patents. Among the inventions are: the electrolytic process for production of fluorine; an improved electronic filter circuit, apparatus for measurement of radioactivity and preparation of organic materials.

The Commission will grant nonexclusive, royalty-free licenses on these patents, as part of its program to make non-secret technological information available for use by industry. Commission-held patents and patent applications released for licensing now total 342.

Applicants for licenses should apply to the chief, patent branch, Office of the General Counsel, U. S. Atomic Energy Commission, Washington 25, D. C., identifying the subject matter by patent number and title. Copies of these patents may be obtained from the U. S. Patent Office.

POLYMERIZATION PLANT CONSTRUCTED IN ITALY

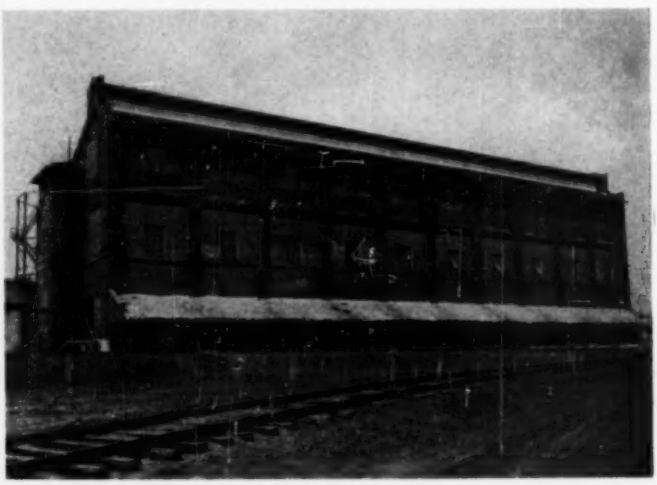
Facilities for the production of polyvinyl chloride resins and compounds manufactured by Monsanto Chemical Co. in the United States are under construction at Porto Marghera, Italy, by Societa Industria Chimica, an Italian company in which Monsanto holds an interest.

Marshall E. Young, director of Monsanto's foreign department, disclosed that a chlorine-caustic plant employing De Nora mercury cells has already been put into operation. Acetylene for producing vinyl chloride monomer, he said, will be made from calcium carbide from a nearby plant in which Societa Edison, major power company of Italy, has an interest. Societa Industria Chimica is a subsidiary of Edison.

The polymerization plant, also being built at Porto Marghera, will be the largest of its kind in Italy.

(*More News on page 28*)

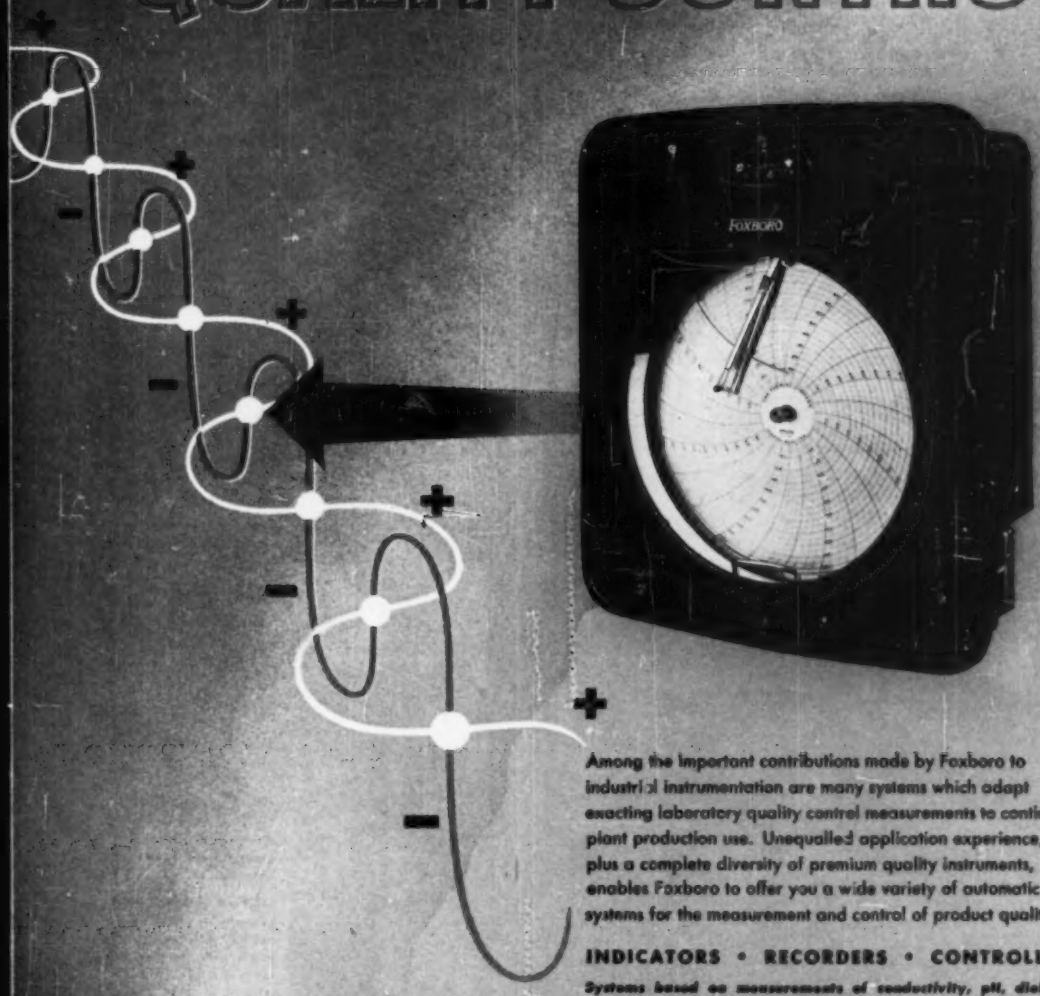
INSTITUTE OF GAS TECHNOLOGY PILOT PLANT



A former gas producer building at Crawford Station of The Peoples Gas Light and Coke Co., Chicago, which was rehabilitated by Peoples at a cost in excess of $100,000 for use by the Institute of Gas Technology as a pilot plant. It contains four 20 by 20-ft. bays with 50-ft. headroom, and two 12 by 60-ft. areas. Public Service Company of Northern Illinois contributed $5000 to increase the plant's power supply to 200 kw.

better instrumentation for

QUALITY CONTROL



Among the important contributions made by Foxboro to industrial instrumentation are many systems which adapt exacting laboratory quality control measurements to continuous plant production use. Unequalled application experience, plus a complete diversity of premium quality instruments, enables Foxboro to offer you a wide variety of automatic systems for the measurement and control of product quality.

INDICATORS • RECORDERS • CONTROLLERS

Systems based on measurements of conductivity, pH, dielectric constant, oxidation-reduction potential, boiling point rise, differential vapor pressure, specific gravity . . .

TRANSMISSION SYSTEMS • CONTROLLED VALVES

FOXBORO

Reg. U. S. Pat. Off.

For over 40 years, specialists in the measurement and control of temperature, pressure, flow, liquid level, humidity . . .

THE FOXBORO COMPANY, FOXBORO, MASSACHUSETTS, U.S.A.

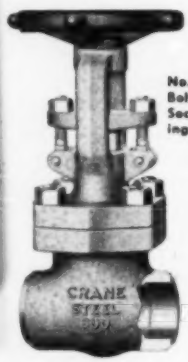
why CRANE 600-pound small steel gates are sure to meet your needs

You can't top these Crane Small Steel Gates for dependable performance on high pressure, high temperature lines . . . for ease of operation . . . for simplified maintenance. That's because they include design features normally found only in larger or more expensive valves.

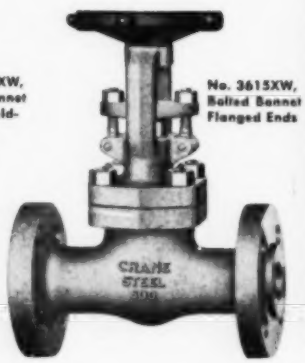
Then too, these Crane valves are available in a choice of types to meet your particular requirements. For example, with union or bolted bonnets; with screwed, flanged, or socket-welding ends; and in trim materials recommended for all common fluids.

GET NEW DESCRIPTIVE CIRCULAR AD-1881

For complete information—including prices—about these longer lasting, easier operating Crane Small Steel Gate Valves. Ask your Crane Representative for your copy, or write direct. No obligation.



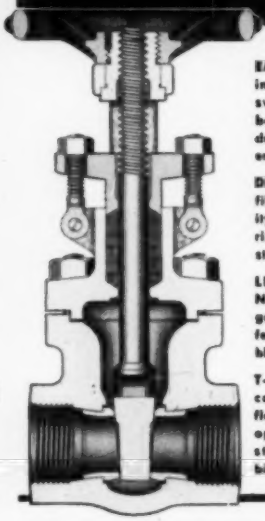
No. 3611XW, Bolted Bonnet Socket-Welding Ends



No. 3615XW, Bolted Bonnet Flanged Ends

UNION BONNET GATE. Screwed ends. Sizes: ¼ to 2-inch. Available in three different trim materials for a wide range of services. Also with socket welding ends

Easy to Operate... Easy to Service



EASY ACCESS to stuffing box assured by swinging gland eyebolts. Improved yoke design provides liberal working space.

DEEP STUFFING BOX filled with high quality asbestos packing rings maintains tight stem seal.

LEAKPROOF BONNET JOINT. Soft iron gasket in male and female joint cannot blow out.

T-HEAD DISC-STEM connection provides flexibility for smooth operation; prevents stem distortion or binding of parts.

Cross-section No. 3607XW, Bolted Bonnet Gate, Screwed

CRANE CO.

General Offices
836 S. Michigan Ave., Chicago 5, Ill.
Branches and Wholesalers Serving All Industrial Areas

VALVES • FITTINGS • PIPE • PLUMBING • HEATING

You've heard of FLUOR QUALITY ...here's proof

You've only to look into a Fluor Counterflo Cooling Tower for the proof of quality—quality of design, of manufacture, of performance, and of appearance. The points illustrated below are just a few of the many features that have earned Fluor Towers their enviable reputation for quality—compare them when next you buy or specify.

GRID DECKS

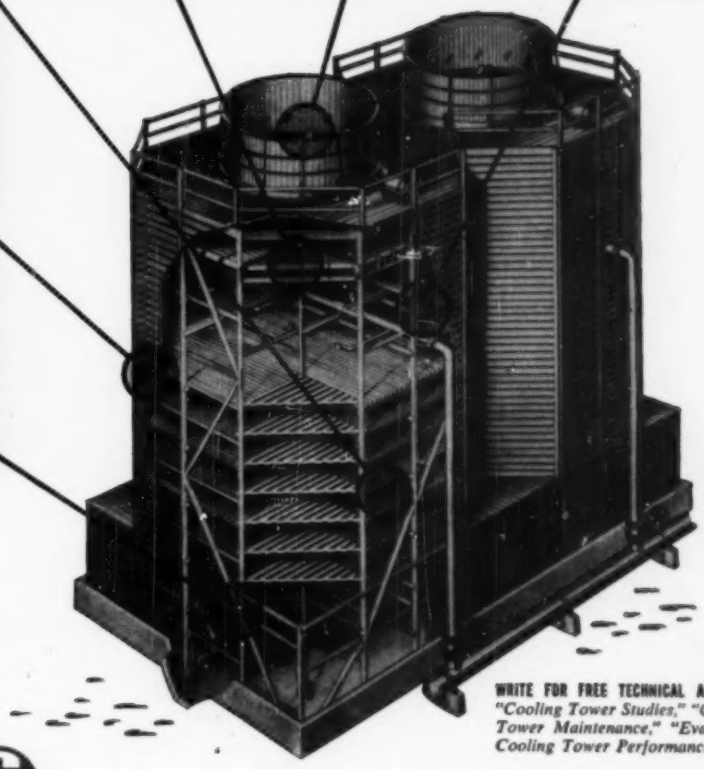
DRIFT ELIMINATORS

STACK and FAN ASSEMBLY

DISTRIBUTING SYSTEM

DOUBLE-WALL SHEATHING

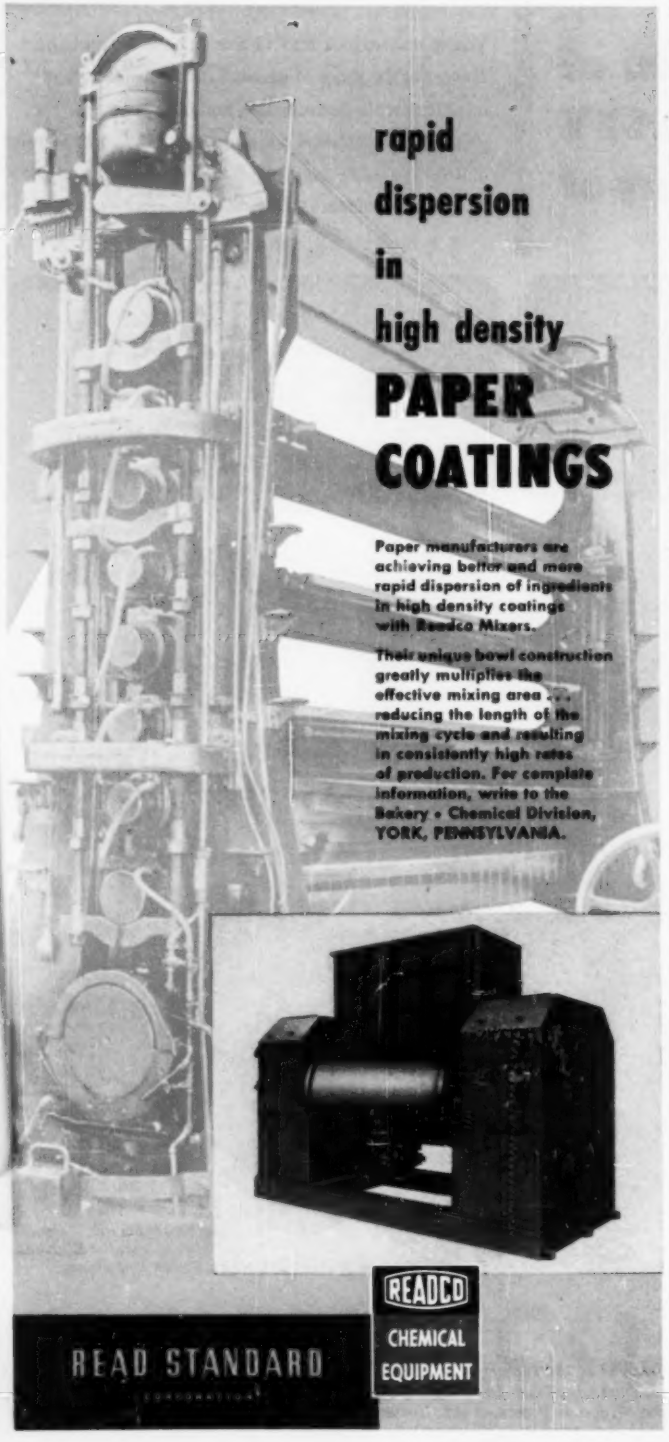
TOWER STRUCTURE



WRITE FOR FREE TECHNICAL ARTICLES: *"Cooling Tower Studies," "Cooling Tower Maintenance," "Evaluating Cooling Tower Performance."*

BE SURE WITH FLUOR

THE FLUOR CORPORATION, LTD., 2500 SOUTH ATLANTIC BOULEVARD, LOS ANGELES 22, CALIFORNIA
New York, Chicago, Boston, Pittsburgh, Tulsa, Houston, San Francisco, Birmingham, Calgary.
REPRESENTED IN THE STERLING AREAS BY: Head Wrightson Processes Ltd., Teesdale House, Baltic Street, London, E.C.1., England


rapid
dispersion
in
high density
PAPER
COATINGS
Paper manufacturers are achieving better and more rapid dispersion of ingredients in high density coatings with Readco Mixers.
Their unique bowl construction greatly multiplies the effective mixing area . . . reducing the length of the mixing cycle and resulting in consistently high rates of production. For complete information, write to the Bakery • Chemical Division, YORK, PENNSYLVANIA.
READ STANDARD
READCO
CHEMICAL
EQUIPMENT

NEWS

(*Continued from page 24*)

PROBLEMS SLOW FISSION PRODUCTS USE

A potential large-scale demand for fission products exists in industry, but many technical and economic problems must be solved before promising new uses for these by-products of the atomic energy program can develop. This was the broad finding and conclusion of Stanford Research Institute from a recent technoeconomic survey of industrial uses of radioactive fission products conducted for the United States A.E.C.

Millions of curies of radioactivity are contained in the process wastes left over from the production of plutonium in the AEC's nuclear reactors. These fission products are known to be a potential source of large quantities of low-cost radiation. Refinement and concentration of the gross fission products, now stored at AEC installations, will undoubtedly be necessary to make them suitable for industrial purposes, the SRI study indicates.

Promising industrial applications for fission products are to be found in various stages of technological development, according to the report. One table sets forth in summary form the approximate state of technological development of selected large-scale potential industrial uses, the fission products required, the maximum value-in-use or competitive price, etc.

Present commercially feasible industrial uses include the activation of phosphors for self-luminescent signs and markers, static eliminators for a variety of industrial processes.

Possible future uses for fission products include industrial radiography, cold sterilization of drugs and foods and portable low-level power sources.

The marketing study emphasizes that the possible industrial advantage in use of fission products lies in their potential ability to produce certain types of radiation at less cost or in more convenient forms than presently available sources.

The technological and marketing problems confronting the Commission in making fission products available to industry are difficult but not insurmountable, according to the report. Reviewed are technical problems involved in the design of processing plants to separate the fission products; in engineering the sources of radioactivity into a form suitable for various purposes; and in supplying fundamental knowledge on which to base development of industrial applications.

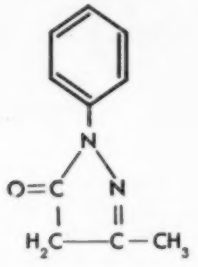
Copies of the report may be obtained for $1.50 from Project 361, Stanford Research Institute, Stanford, California.

(*More News on page 32*)

one of many **DOW** chemicals
serving the Pharmaceutical Industry

3-Methyl-1-Phenyl-5-Pyrazolone

Used in the preparation of pharmaceuticals and as a dye intermediate.



PROPERTIES	
White to slightly yellow powder	
Boiling point at 17 mm. Hg	191°C.
Melting point	128.9°C.
Molecular weight	174.2

THE DOW CHEMICAL COMPANY • MIDLAND, MICHIGAN

Send for Experimental Sample

The Dow Chemical Company
Dept. FC-3 A
Midland, Michigan

Please send me an experimental sample of 3-Methyl-1-Phenyl-5-Pyrazolone.

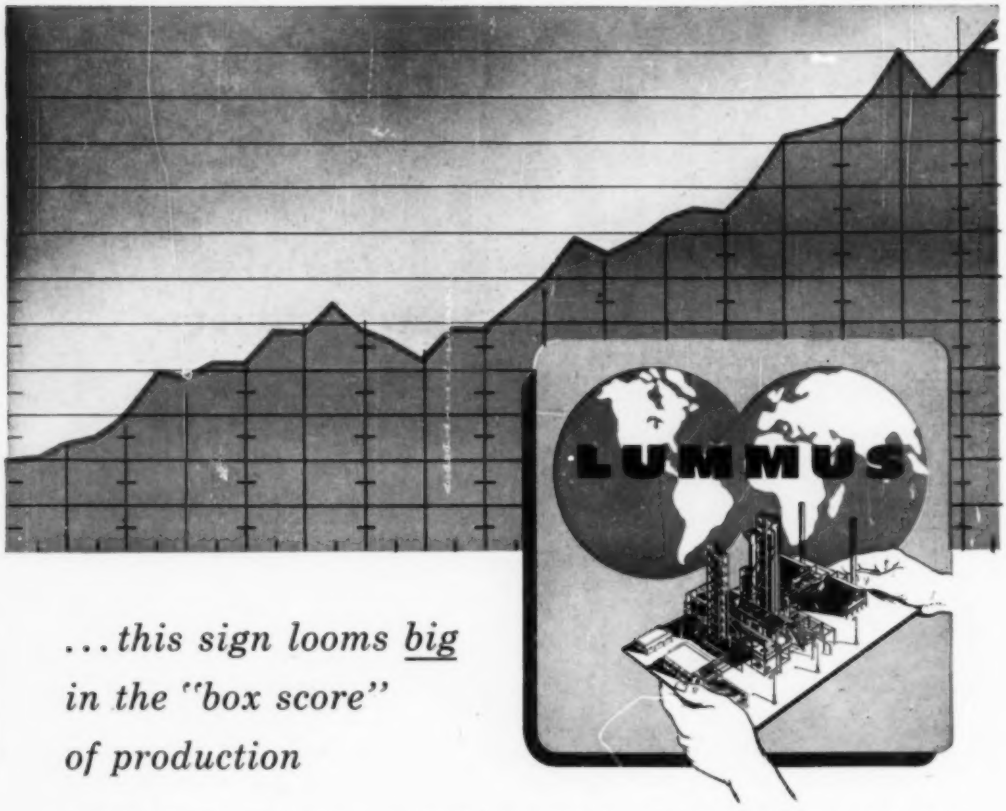
Name _____ Title _____

Company _____

Street _____

City _____ State _____

DOW
CHEMICALS
INDISPENSABLE TO INDUSTRY
AND AGRICULTURE



...this sign looms big in the "box score" of production

For better than sixty years the Lummus sign has meant ex*cellence* in the designing, engineering and constructing of petroleum refineries and chemical plants. It means the same today. And you need take only a short mental jump to see its importance in the days ahead, as oil refiners and chemical producers are called upon to break and re-break production records.

Let's look at a partial "box score" of Lummus' current contributions toward these world-wide objectives. In the U. S. and abroad, Lummus is engaged in seven catalytic cracking projects—as well as in providing alkylation facilities —to meet the record-breaking demand for superior aviation and motor fuels.

Lummus currently has seven ethylene units "on the go" in Europe and the U. S.—plants which will operate with telling effect in supplying a vital basic raw material. One project—the Gulf Oil Corporation unit at Port Arthur, Texas—is the world's largest ethylene unit. It will produce nearly 2½ billion cubic feet yearly, increasing total U. S. production of ethylene by about 12%.

Isn't this a reassuring record for you to tie to? It strongly suggests that you think of Lummus first in your plans for petroleum refinery or chemical plant expansion.

THE LUMMUS COMPANY

385 MADISON AVENUE, NEW YORK 17, N. Y.

HOUSTON • CHICAGO • LONDON • PARIS • CARACAS

DESIGNING ENGINEERS AND CONSTRUCTORS FOR THE PETROLEUM AND CHEMICAL INDUSTRIES

GLYCERINE

IMPORTANT FOR PROTECTIVE COATINGS...

...IMPERATIVE FOR NATIONAL DEFENSE!

Why do so many top-quality coatings rely on Glycerine-derived alkyd resins or ester gums? These versatile components add film toughness . . . long life . . . and improved color retention to paints and varnishes. Special finishes depend on them, too. Corrosion-inhibitors, de-icing paints, anti-rust compounds, grease-proof coatings – all take advantage of Glycerine's outstanding range of properties!

Today, Glycerine is in strong national demand. Especially for coatings that must meet military specifications. So if you find supplies temporarily short, here's why: Glycerine's outstanding versatility is answering both civilian and defense coating problems at the same time!

GLYCERINE PRODUCERS' ASSOCIATION
295 Madison Ave., New York 17, N. Y.

New POTTER Electronic FLOWMETER and TACHOMETER

Improved design eliminates

★ BEARING MAINTENANCE
★ HIGH PRESSURE DROP
★ BEARING FRICTION

The improved Potter Electronic Flowmeter (patent pending) combines extreme accuracy with freedom from maintenance. This new design eliminates thrust bearings, high pressure drop, and bearing maintenance.

The Potter Flowmeter comprises a flow sensing unit having a hydraulically balanced rotor and magnet rotating within a compact non-magnetic housing, and an external pickup coil connected to an electronic integrator or totalizer, or both.

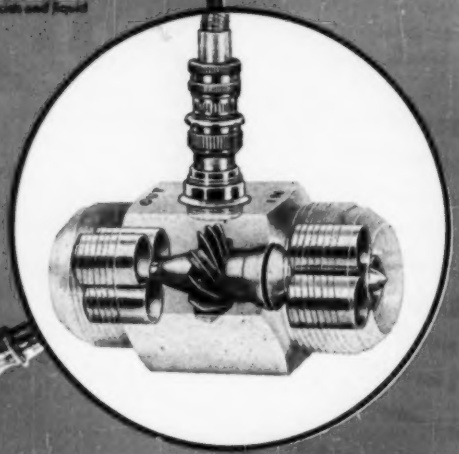
ACCURATE within ±½%

Since the novel, high-efficiency rotor spins in a freely balanced position within a venturi, its blades operate with practically no slippage. Fluid viscosity, pressure, temperature, and specific gravity only slightly affect the volumetric flow rate. Accuracy is maintained within ±½%. Electric impulses from the rotor are conducted to a combination electronic integrator and totalizer. Rate of flow can be read or recorded either directly or remotely, and total flow is indicated on a resettable magnetic Veeder-Root counter.

We will gladly help you solve your flow measuring problems.

APPLICATIONS

Potter Flowmeters accurately measure flow. Especially suitable for highly corrosive liquids, gases, acids and liquid oxygen.



SEND FOR NEW BULLETIN 1050 which gives full information, pressure drop chart, ranges, sizes, and operational data.

POTTER AERONAUTICAL CO. 87 Academy St., Newark 2, N. J.

(*News continued from page 28*)

U.N.E.S.C.O. CONFERENCE SCHEDULED FOR JANUARY

A keynote address on the place of the United Nations in the world of 1952, to be given at the first plenary session, will set the tone for the Third National Conference, United States National Commission for UNESCO, to be held at Hunter College, N. Y., Jan. 27-31.

Another feature of an early session will be the showing of a documentary presentation highlighting the work of the United Nations and the Specialized Agencies.

Having as its theme, "The United Nations—Man Helping Man," the conference will focus on means of improving citizen understanding of and participation in world affairs.

Addresses will be given by high United Nations and government officials and by other prominent UNESCO leaders. Use of the theatre, films, radio, and television in creating a better understanding of world problems will be thoroughly explored at the conference. The Educational Film Library Association is preparing a list of documentary films on international themes.

"Building Interest through Mass Communication" will be the topic of a general session at which leaders in radio, television, films, and the press will evaluate the accomplishments and potentialities of these media in contributing to understanding world problems.

Exhibits of national and international agencies and organizations will form an integral part of the conference. Among the exhibitors will be the United Nations and several of its Specialized Agencies, and numerous national organizations.

E. W. REID ACCEPTS S.C.I. MEDAL AT DINNER

"The importance of corn in the development and growth of our country is little realized, nor is it generally known that due to this grain, the Americas are the only countries in the world that have never had a major famine." This sentiment was expressed by Ernest W. Reid, member of A.I.Ch.E., in his acceptance of the Chemical Industry Medal of the American Section of the Society of Chemical Industry before a gathering of 350 American industrial chemists at the Waldorf-Astoria Hotel, New York, Oct. 27. The award—"for conspicuous service to applied chemistry" was titled "Chemistry and Agriculture in Human Welfare." Dr. Reid has been president of the Corn Products Refining Co. since April, 1951.

E. R. Weidlein, director of the Mellon Institute, discussed "The Accomplishments of the Medalist."

(*More News on page 44*)

instantaneous

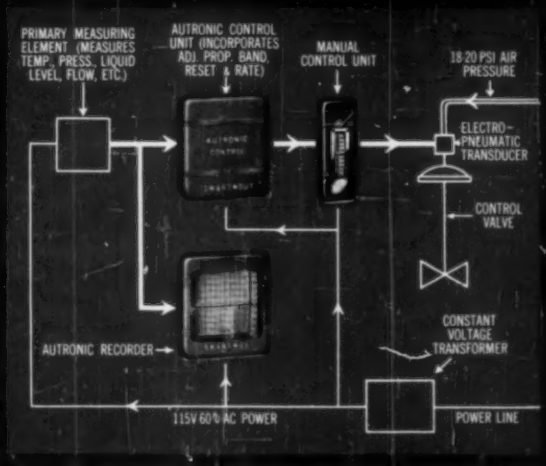
all-electronic control

of pressure

temperature

flow

and level . . .


PRIMARY MEASURING ELEMENT (MEASURES TEMP., PRESS., LIQUID LEVEL, FLOW, ETC.)
AUTRONIC CONTROL UNIT (INCORPORATES ADJ. PROP. BAND, RESET & RATE)
MANUAL CONTROL UNIT
18-20 PSI AIR PRESSURE
ELECTRO-PNEUMATIC TRANSDUCER
CONTROL VALVE
AUTRONIC RECORDER
CONSTANT VOLTAGE TRANSFORMER
115V 60% AC POWER
POWER LINE

The new Swartwout Autronic Control System brings new speed, new accuracy to your process controls. Without mechanical motion of any kind this new *all-electronic control system* spans distance between primary element and control element *without interval*. Measuring . . . analyzing . . . correcting —the Autronic System keeps your process on stream . . . assures quality product by controlling pressure, temperature, flow and level properly, instantaneously *without cycling, drifting, shifting.* Call in our engineering representative to explain how Swartwout Autronic Controls will bring new accuracy to *your* process and power instrumentation and control. Or write *today* for literature on the new Swartwout Autronic Control System.

A-6072

Swartwout *Autronic* CONTROL SYSTEM

THE SWARTWOUT COMPANY • 18511 EUCLID AVENUE • CLEVELAND 12, OHIO

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Surfactivity & Syndets

Surface Activity. J. L. Moillet and B. Collie. D. Van Nostrand Co., Inc., New York. (1951) 379 pp. $12.50.

Reviewed by Clyde McKinley, Chemical Engineer, General Aniline Works, Grasselli, N. J.

A WORTH-WHILE book for the research worker, who is interested in surface-active agents and in prediction and control of interfacial processes. The book will be of particular value to those searching for insight into the relationship between molecular constitution and surface activity. This relationship, fundamentally physical-chemical in nature, is helpfully expounded throughout the book with the result that the book has a strong physical-chemical flavor that should make it very useful to the chemically trained research man.

The first third of the book presents the physical chemistry of surface-active agents and interfacial processes going into detail on the states of solution of surface-active agents, the mode of adsorption of surface-active agents at interfaces, and such interfacial processes as wetting, flocculation and deflocculation, protective colloid action, mechanical phase-subdivision, emulsification, dispersion, and precipitation. This section will aid the research worker in the formulation of his own ideas and will orient a newcomer to the field.

The second third of the book presents technical applications of synthetic surface-active agents. A generalized physical-chemical treatment is given such technical problems as wetting-out, waterproofing, preparation of emulsions, dispersion of solids, and removal of dirt through use of a detergent. Here again, as in the first third of the book, the discussion will stimulate growth of ideas and clarify understanding.

The last third of the book classifies and describes the major synthetic surface-active agents. In a factual manner the chemical structure of all the major examples of anionic, cationic and nonionic surface-active materials is set forth. This well-written section relies largely upon patent specification and the B.I.O.S. and F.I.A.T. reports on German industry.

Three indices are included: author, trade name, and subject.

Look to the Law

Industrial Water Pollution—Survey of Legislation and Regulations. Marvin D. Weiss. Chemonomics, Inc., New York. (1951) 141 pp. $5.00.

Reviewed by E. B. Besselievre, Sales Engineer, Dorr Co., Stamford, Conn.

IN the increasing emphasis on stream pollution by industrial wastes and the preventive measures to be taken, too little attention has been given to the regulations, statutes and other legislative items which impose restrictions, duties and burdens upon industry.

The Federal government, nearly every state and many municipalities have laws, regulations, ordinances, etc., which control and regulate amount, type and composition of wastes that an industry may turn into a stream.

In numerous states, commissions and boards have been created which have set up classifications of their streams, indicating their ultimate use and possible use as receptacles of industrial wastes, treated, or untreated.

This pamphlet is valuable in giving the general Federal law and state legislation, control factors, classification of streams, where adopted, and other selected data on the composition of several wastes. It omits, however, many other phases entering into the solution of an industrial waste problem, such as local municipal codes, public policy, political expediency, local prejudices, etc., all of which are equally important for an industrialist to know if he is to correct a pollution complaint in an economical manner.

It would seem that considerable information contained in the pamphlet is duplicated to some extent in two publications of the United States Public Health Service, namely, "Water Pollution in the U. S.," U. S. Public Health Service, Washington, D. C. (May 1951), and "Suggested State Water Pollution Act and Explanatory Statement," Federal Security Agency, U. S. Public Health Service, Division of Water Pollution Control (October, 1950), or in similar publications issued by the several states. However, for one who does not wish, or does not have the time, to investigate these individual sources for himself the pamphlet serves a worthy purpose as a briefed compilation.

Fuels Without "Frills"

Fuel Oil Manual. Paul F. Schmidt. The Industry Press, New York. (1951) 160 pp. $3.50.

Reviewed by Eugene Ayres, Tech. Asst. to Exec. Vice-Pres., Gulf Research & Development Co., Pittsburgh, Pa.

IT IS not often that the usefulness of a book goes beyond the description on the wrapper. This volume is an exception for its claims are too modest. The book should prove to be useful not only to the industrial consumer of fuel oils but also to those who engage in manufacture of fuel oils, its storage, its transportation, and its sales. Furthermore, the book is an excellent introduction for those starting research on fuel oils.

There are no "frills" in the book. It is not particularly well written. It is not original in conception or content. It does not pretend to contain anything not already familiar to the well-informed technologist. But it is well organized, thorough, up to date, and accurate. In addition it is straightforward and simply expressed. The author is to be congratulated.

Books Received

Selective Toxicity. Adrien Albert. John Wiley & Sons, Inc., New York. (1951) 228 pp. $1.75.

Phase Microscopy—Principles and Applications. Alva H. Bennett, Helen Jupnik, Harold Osterberg, and Oscar W. Richards. John Wiley & Sons, Inc., New York, (1951) 320 pp. $7.50.

Microbial Decomposition of Cellulose. Ralph G. H. Siu. Reinhold Publishing Corp., New York. (1951) 531 pp. $10.00.

The Surface Chemistry of Solids. S. J. Gregg. Reinhold Publishing Corp., New York, (1951). 297 pp. $8.50.

Physical Biochemistry. Second Edition. Henry B. Bull. John Wiley & Sons, Inc., New York. (1951) 355 pp. $5.75.

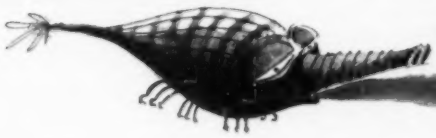
Introduction to Number Theory. Trygve Nagell. John Wiley & Sons, Inc., New York, (1951) 310 pp. $5.00.

Elements of Plant Protection. Louis Pyenson. John Wiley & Sons, Inc., New York. (1951) 538 pp. $4.96.

Organic Chemistry. J. P. Wibaut. (Continuation of "Textbook of Organic Chemistry" by A. F. Holleman.) Elsevier Publishing Co. Amsterdam—C. Netherlands. (1951) 660 pp. $9.00.

Corrosive fumes...

Salt air...



Hot air...

Moist air...

SO WHAT!

"KARBATE" BRAND

impervious graphite pipe takes it all in stride!

Have you thought about corrosion *on the outside* of your plant piping? Fumes, salt air, hot air, moist air, can eat up *the exterior* of piping, fittings, valves, pumps, and other equipment around a chemical plant. And it costs money to protect ordinary metal surfaces. You have to sandblast, use special coatings, and even then you find the corrosion creeping in and chewing up the equipment...

NOT SO WITH "KARBATE" IMPERVIOUS GRAPHITE!

Here are the advantages:

- **No exterior protection needed**
- **Both acid-resistant and alkali-resistant**
- **Light in weight, easy to machine and assemble**
- **No metallic contamination of product**
- **Immune to thermal shock**
- **Very high thermal conductivity**

The term "Karbate" is a registered trade-mark of Union Carbide and Carbon Corporation

NATIONAL CARBON COMPANY
A Division of Union Carbide and Carbon Corporation
30 East 42nd Street, New York 17, N. Y.
District Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco
IN CANADA: National Carbon Limited, Montreal, Toronto, Winnipeg

Other NATIONAL CARBON Products

HEAT EXCHANGERS • PUMPS • VALVES • PIPING • TOWERS • TOWER PACKING • BUBBLE CAPS • BRICK • STRUCTURAL CARBON • SULPHURIC ACID CUTTERS • HYDROCHLORIC ACID ABSORBERS

for SAFE, SURE SERVICE SPECIFY CHIKSAN

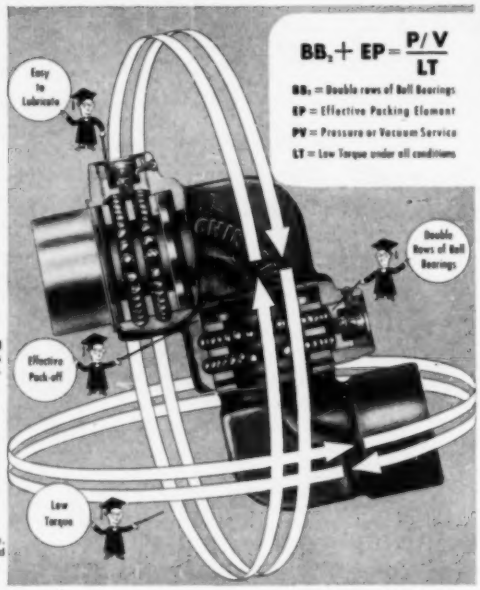
Standard Swivel Joints. For pressures from 125 psi. to 15,000 psi.

High Temperature Swivel Joints. For temperatures to 500°F. M.W.P. 700 psi.

Rotating Joints. For 150-lb. steam, brine, etc. Adapted for siphon return line.

Sanitary Swivel Joints. For Food Processing, Dairies, Bottlers, etc.

Hydraulic Swivel Joints. For pressures to 3,000 psi.


$BB_2 + EP = \frac{P/V}{LT}$
BB_2 = Double rows of Ball Bearings
EP = Effective Packing Element
PV = Pressure or Vacuum Service
LT = Low Torque under all conditions
Easy to Lubricate
Double Rows of Ball Bearings
Effective Pack-off
Low Torque

For over a quarter-century, here at CHIKSAN, we have specialized *exclusively* on developing and designing Swivel Joints* for all purposes... on manufacturing them to our rigid standards of precision... and on following through in the field to check performance under all sorts of conditions. That's why there is no substitute for CHIKSAN *Ball-Bearing* Swivel Joints* when it comes to efficient service with maximum safety... longest life... and minimum maintenance.

It costs you nothing to take full advantage of CHIKSAN's *specialized* experience. CHIKSAN Engineers will gladly cooperate with you in designing flexible lines to meet your specific requirements.

WRITE FOR CATALOG NO. 50-C. REPRESENTATIVES IN PRINCIPAL CITIES—SOLD BY LEADING SUPPLY STORES EVERYWHERE

*For full 360° rotation in 1, 2 and 3 planes. Unlimited flexibility in pipe lines is secured merely by arranging swivels in proper sequence. Over 500 different Types, Styles and Sizes for pressures to 15,000 psi; temperatures to 500°F.; pipe sizes from ¾" to 12" and larger.

CHIKSAN

CHIKSAN COMPANY

AND SUBSIDIARY COMPANIES

Chicago 3, Ill. BREA, CALIFORNIA Newark 2, N. J.

WELL EQUIPMENT MFG. CORP. HOUSTON 1, TEXAS

CHIKSAN EXPORT CO. BREA, CALIFORNIA NEWARK 2, N. J.

BALL-BEARING SWIVEL JOINTS FOR ALL PURSUITS

(Continued from page 17)

KARL W. RAUSCH, JR.

division at Pittsfield, Mass. A native of Cleveland, Ohio, the Rausch family moved to Ulilson, N. C., where he graduated from the Charles L. Coon High School in 1947, and was a member of the National Honor Society. While at Yale he joined Alpha Chi Sigma professional fraternity, and was elected Master of Ceremonies and later elected Vice Master Alchemist. He was also a member of the A.I.Ch.E. Student Chapter.

Second prize in the contest went to Kenneth R. Cantwell, a recent graduate of the University of Oklahoma. A native of Wyandotte, Okla., he graduated in 1947 from Wyandotte High School, was valedictorian of his class, and a member of the Oklahoma State Honor Society. Cantwell served as vice-president of the Engineers' Club while completing a pre-engineering course at Northwestern A. & M. College, and graduated in 1949, again as valedictorian of his class. While attending the University of Oklahoma he served as treasurer of the A.I.Ch.E. Student Chapter, and held membership in the Senior Men's Honor Society and Engineers' Club. A member of Alpha Chi Sigma professional chemical fraternity, Tau Beta Pi, he was also elected associate member of The Society of Sigma Xi, national scientific research organization. He is at present with the chemical engineering division of Phillips Petroleum Co., Bartlesville.

Third prize went to Preston W. Grounds, Jr., a graduate of Northwestern University. A native of Oak Park, Ill., Grounds spent 13 months in the U. S. Navy, and entered Northwestern University Technological Institute in March, 1947. He spent cooperative work periods with the Du Pont Co. in Richmond, Va., and graduated with a B.S. in chemical engineering in June,

1951. He was a member of the A.I.Ch.E. Student Chapter, and is a member of Tau Beta Pi, and Alpha Chi Sigma. He was awarded a tuitional scholarship and research assistantship at Northwestern, and is at present working toward an M.S. in chemical engineering.

Honorable mention in the contest went to Francis O. Whipple, a graduate of Reed College and Oregon State College, where he received his M.S. degree in chemical engineering, and is now working towards his Ph.D. degree;

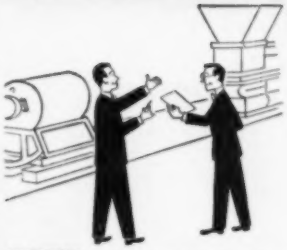
KENNETH R. CANTWELL

Her[illegible] graduate of Polytechnic Institute of Brooklyn, cum laude, who is now field engineer in the development section of the organic chemical division of the Du Pont Co. in Wilmington; and Foster W. Rennie, a graduate of Clarkson College of Technology. Rennie, upon graduation, was employed by Du Pont Co. as an engineer in the engineering department is now on extended active duty as a 2nd lieutenant in the Corps of Engineers, a commission he received upon graduation.

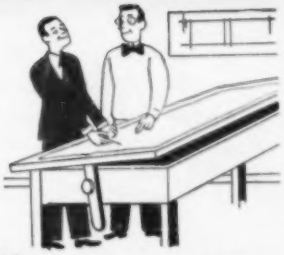
PRESTON W. GROUNDS, JR.

SOME "DO'S and DON'T'S" IN BUYING DRYING EQUIPMENT...

(that will save time, money and headaches)

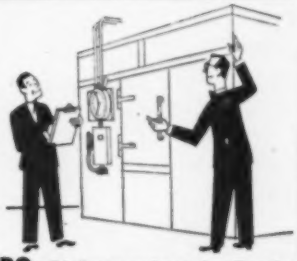


DON'T wait until the last minute to consider drying equipment—after your other process equipment has all been ordered or even installed.



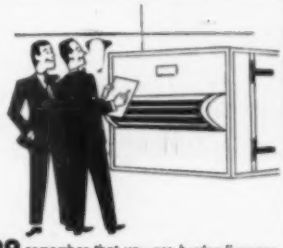
DO call in Proctor engineers while your process is in its earliest planning stage. Drying is a major link in the over-all process—and may easily affect—or be affected by other equipment.

DON'T spend hours of your own men's time trying to work out your own design for a drying system. This is costly in man hours, effort and dollars.



DO call in Proctor engineers who will conduct necessary tests in their well-equipped laboratory at no cost to you and make recommendations for a system that will be designed to your specific needs.

DON'T base your final decision in the selection of a drying system entirely on the price tag or initial investment. Some customers have found this a costly experiment.



DO remember that you are buying "guaranteed performance" when you invest in a Proctor system that is designed to meet your needs and which will be meeting those needs before Proctor considers the transaction closed.

DO acquaint yourself more thoroughly with the Proctor approach to solving drying problems by writing today for Bulletins 343 and 361.

PROCTOR & SCHWARTZ INC.

630 TABOR ROAD • PHILADELPHIA 20, PA.

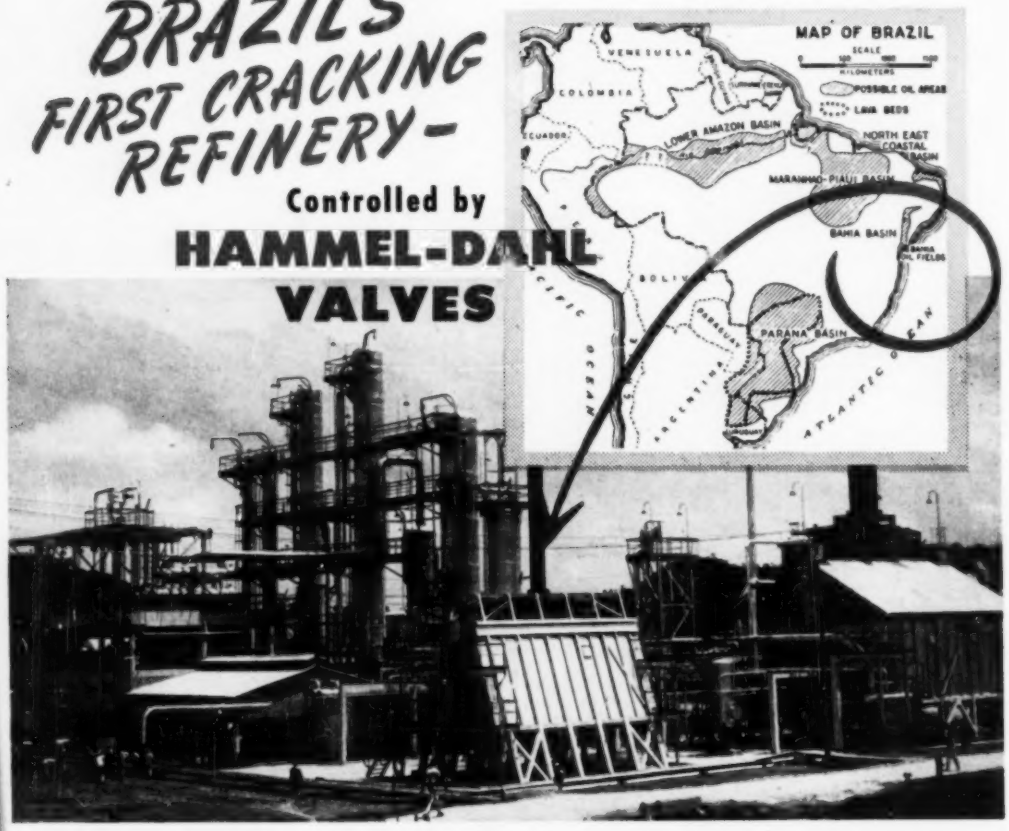
AUTOMATIC CONTROL EQUIPMENT

ENGINEERED DESIGN BY **HAMMEL-DAHL**

BRAZIL'S FIRST CRACKING REFINERY—

Controlled by

HAMMEL-DAHL VALVES



This new 2500 barrel per day Refinery — the first to produce cracked gasoline in Brazil — has recently been placed on stream at Bahia for Refinaria Nacional de Petroleo, S. A., by The M. W. Kellogg Company, refinery and chemical engineer-contractors of New York City.

Consult your nearest H-D Sales Engineer for Precision Control of your Process

HAMMEL-DAHL COMPANY

243 RICHMOND STREET, PROVIDENCE 3, R. I., U.S.A.

Albany Boston Buffalo Chicago Cincinnati Cleveland Denver Detroit Houston Kalamazoo
Kansas City Kingsport, Tenn. Los Angeles New Orleans New York Pittsburgh Salt Lake City
San Francisco Seattle Springfield, Mass. St. Louis Syracuse Toledo Tulsa Wilmington, Del.

Chemical Engineering Progress

DATA SERVICE

EQUIPMENT

Here is a convenient CHEMICAL ENGINEERING PROGRESS service for you — in every issue — concise, authentic reports on what is new and improved in equipment and supplies, chemicals and materials — including brief reviews of the descriptive free literature available.

To assure an easy way of keeping abreast of new equipment, new chemicals, and new developments in the field, obtain the accurate descriptions on what the manufacturer has to offer right from the manufacturer. Go through this reader service section right now — then tear out the special order card — encircle the identifying number of the literature you desire — sign and mail — that's all you have to do — no postage necessary.

1 • *ALKALI RESISTANT GLASS.* A new glass for lining reaction vessels, which is resistant to pH between 10 and 12, and temperatures up to 212° F. is announced by the Pfaudler Co. A complement to Pfaudler's acid resistant glass-lined tanks. Data on alkali resistant glass compared with standard glass indicates a much improved life and rate of corrosion resistance.

2 • *THERMOMETER MAGNIFIER.* A magnifier with spring clamps for snapping on to a standard thermometer, which magnifies a section of the thermometer. Visible 6 ft. away. Fisher Scientific Co. For plant thermometers in awkward positions. Cost $2.25 each.

3 • *TEST FILTER.* For testing high-speed, pressure-leaf, filtration methods on a small scale, Niagara Filter Corp. announces a new small-size vertical pressure-leaf filter. For determining rate of filtration, quality of filtrate, characteristics of filter aids, optimum filter-aid quantities, etc. Tempered Pyrex glass tank cylinder for visual examination of filter cake and liquid flow. Other parts are stainless.

4 • *SURFACE THERMOMETER.* For checking surface temperature accurately, a new surface temperature thermometer by the Pacific Transducer Co. Will check temperature of pipes, dies, molds, refrigerators, freezers, etc. Affixed by silicone grease which holds thermometers through range of temperature from 0° to 300° F. in 2° increments.

5 • *NEW CARBIDE.* An entirely new tungsten and cobalt-free metallic carbide announced by Carboloy, department of General Electric Co. High resistance to abrasion, erosion, and corrosion, lighter weight, coefficient of thermal expansion approximately the same as steel. Used in valves, centrifuge blades, etc., where abrasion, corrosion, and erosion resistance is valuable.

6 • *RESPIRATOR FOR RADIO ACTIVITY.* To protect workmen exposed to beryllium, radio-active dusts, etc., a new respirator developed by Mine Safety Appliance Co. Filter efficiency high against particles $\frac{3}{10}$ μ in size. Uses special asbestos fibers. Designed also to fit welding helmets.

7 • *CARBOYPUMP.* For removing corrosive liquids from carboys, Laboratory Industries, Inc., announced a new hand pump for laboratory, pilot plant, and plant use. Fabricated from heavy Pyrex tubing, check valves of Pyrex, pumping ring of Teflon. Eliminates contamination, uses positive displacement method of pumping.

8 • *CONTINUOUS MILL.* A new, heavy duty continuous ball or tube mill in production by Patterson Foundry & Machine Co. Adaptable to fine or coarse, wet or dry, open- or closed-circuit grinding. Hollow trunnions are provided for continuous feed and discharge of materials. Continuous flushing of grit from bearings is accomplished by an oil-circulating system. A plastic sleeve bearing has available a combination water cooling and lubricating system. Sizes range from 2 ft. to 10 ft. diam.

9 • *OIL FILTERS.* The Hilliard Corp. with an improved line of lubricating, fuel, and industrial oil filters. Features swing-bolt head for quick open

Mail card for more data ▶

Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18
19	20	21	22	23	30	31	32	33	34	35	36	37	38	39	40	41
45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61

PLEASE TYPE OR PRINT

Name ..... Position .....

Company .....

Address .....

City ..... Zone State .....

Chemical Engineering Progress

DATA SERVICE

ing of filter covers, and a lifting device. Available in both filter cartridge and repackable type. Capacities ranging from ½ gal./min. to 1000 gals./min. Used in filtering transformer insulating oils and other oils from hydraulic equipment, air compressors, steam engines, turbines, etc.

10 • ***IN-LINE NOZZLE.*** For pneumatic atomizing systems where space is limited and nozzle must be mounted in a straight line position, Spraying Systems Co. has designed a new pneumatic atomizing nozzle with the inlets for air and liquid connections in line with the spray nozzle. Previously pneumatic nozzles were designed with inlets in opposed positions to line of spray.

11 • ***HELIPATH STAND.*** For measuring plastic materials, regardless of a degree of thixotropy, Brookfield Engineering Laboratories, Inc., with a new Helipath stand which makes it possible to obtain consistent measurements in centipoise values of grease, putty, gelatine, etc. Adapts rotational viscometers to materials formerly believed unsuited for viscosity measurements by this method.

12 • ***MASTIC FEEDER.*** For uniform feeding of sticky, mastic, plastic-type materials, i.e., filter press cake, sludge, etc., a Com-Bin feeder of the Pulva Corp. Has cylindrical shell mounted concentrically on a vertical shaft which also holds a circular plate. Material feeds from center of the cylinder through a gap between the plate and revolving cylinder and is removed by a stationary plow, which extends through the gap into the material to be fed. Holds a charge of 5000 lbs. Material is discharged at the rate of 2000 lbs. Other sizes available ranging from 5 lbs. to 50 tons.

14 • ***PORTABLE VISCOSIMETER.*** For quick determination of the viscosity and gel strength a Fann V-G meter. Produced by the Geophysical Machine Works. Weighs 9 lbs. and operates on a 6-volt storage battery. A catalog of eight pages covering complete line of the company's fluid testing equipment available.

15 • ***RADIATION MONITORING.*** A service offered by Technical Associates, Inc., of radiation health monitoring. Uses a film badge service. Badges are sent at weekly intervals, and are returned for processing and measurement. Company furnishes a weekly report on exposure.

16 • ***TRIPLEX PUMP.*** A heavy duty triplex pump for heavy duty hydraulic service has been introduced by Kobe, Inc. Available in 15, 30, and 50 hp.? pressure ratings up to 5000 lbs./sq.in. Special equipment up to 20,000 lbs./sq.in. Developed for hydraulic oil-well pumping. Manufacturer has now extended use to other markets including the process industries.

17 • ***NEW VALVE.*** A cone-shaped seal valve which uses fluid pressure to make a leak-tight seal is announced by the Rodic Chemical and Rubber Corp. The seal is closed in the same direction as the movement of the fluid, the cone-shaped washer pressing against the seat. Special rubber seal is used to withstand corrosive action of oil, grease, steam, etc.

18 • ***RESIN DISSOLVING TANK.*** Brighton Copper Works, Inc., with a new dissolving tank for large lumps of solid resin. Equipped with explosion-proof motor for use with solvents. Agitator shaft ball-bearing mounted, stainless steel construction.

19 • ***REFRASIL.*** A fibrous silica insulation originally developed for jet aircraft now available for industry by H. I. Thompson Co. Maximum insulation of 1800° F. Comes in either blankets, batts, cords, sleeves, bulk, tapes, fiber, etc. For high temperature thermal insulation, electric space separators, filtration of corrosive or high temperature materials, plastic laminates, etc.

20 • ***NEW FIBER GLASS PLASTIC.*** A fiber glass and plastic resin combination with a high impact strength made by Plaskon Division, Libbey-Owens-Ford Glass Co. Sold in two forms. Essentially an alkyd molding compound. For use in plastic equipment which requires high strength.

21 • ***PLASTIC PIPE.*** A plastic pipe in flexible, semirigid, and rigid types from nonplasticized polyvinyl chloride by Munray Products, Inc. Sizes up to 2 in. Good for temperatures below 170° F. and for conducting acids, alkalies, salts, oils, greases, etc. Can be machined, welded, threaded. Plain end or flanged pipe furnished. Physical properties, chemical resistance data available.

Postage Will Be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

BUSINESS REPLY CARD

First Class Permit No. 48890, Sec. 34.9, P. L. & R., New York, N. Y.

Chemical Engineering Progress

120 East 41st Street

New York 17,

New York

USE THESE CARDS

Chemical Engineering Progress

DATA SERVICE

22 • *CORROSIVE PROOFING.* A system of flame-spraying polyethylene to mild steel has been perfected by Linde Air Products Co. Successfully resists corrosive chemicals. Polyethylene sprayed from a gun and coating is approximately .05 in. thick when applied.

23 • *WELDING PIPE FITTINGS.* Key Co. with a line of alloy steel welding pipe fittings and flanges. New design, of greater wall thickness throughout and added thickness at stress areas. Meets usual standards. Available in all sizes and schedule numbers.

CHEMICALS

30 • *NITROGEN TETROXIDE.* A safety manual from Solvay Process Division on the use of nitrogen tetroxide in industry. Covers physiological effects, medical care, safety measures, unloading and handling, analytical methods and references. Data sheets cover vapor pressure and construction of cylinders.

31 • *PLASTICIZER.* Technical data sheets on Santicizer 8 (mixture of N-ethyl ortho and para toluene sulfonamides). For use as a plasticizer for coating adhesives and molding compounds. Three sheets cover use and properties for both molding, adhesives, and coatings. From Monsanto Chemical Co.

32 • *EMULSIONS.* Acrylic ester copolymer dispersions for adhesive binders and saturants. American Polymer Corp. product. The dry material yields flexible, water-clear, nonoxidizable films. Continuous films formed at room temperature. Contain no plasticizers and are free from embrittlement and plasticizer migration.

33 • *ALIPHATIC AMINES.* Three new, high molecular weight aliphatic amines are in production by Rohm & Haas Co. Samples and technical literature giving physical properties, and instructions for reactions, are available. The new amines range from 12 to 18 carbon atoms in length and are mixtures of isomeric products. Uses are in corrosion inhibitors, bactericides, insecticides, detergents, etc.

34 • *AMINE PIPERIDINE.* Small quantities of saturated aromatic amine piperidine are available for research and development. An Eastman Kodak Co. organic chemical used as a condensing agent, and a component of quarternary ammonium salts.

35 • *GLYOXAL AND PYRUVIC ALDEHYDES.* A technical bulletin describing these aldehydes, from Carbide & Carbon Chemicals Co. Physical and chemical properties, etc. Used in treating and sizing paper, and textiles, for adhesives, coatings, etc. Pyruvic compound used for its insolubilizing properties, as an aid in deposition of silver, etc.

36 • *BLOWING AGENT.* For rubber and plastic sponge products a chemical blowing agent from the United States Rubber Co. Chemically is benzene sulfonyl hydrazide. Stable at normal temperatures, but decomposes at temperatures above 135° C. Can be used either with natural or synthetic rubber.

37 • *TETRACHLOROBENZENE.* Hooker Electrochemical Co. in commercial production of 1, 2, 4, 5-tetrachlorobenzene an intermediate for the manufacture of 2, 4, 5-trichlorophenoxy acetic acid. The latter is a hormone-type herbicide. Technical data sheet covering typical properties, etc.

38 • *DIETHYL SUCCINATE.* A technical data sheet on diethyl succinate as a chemical intermediate from Monsanto Chemical Co. Typical in data sheet form gives properties, chemical reactions, bibliography. Of potentiality in the synthesis of ring compounds.

39 • *CARNAUBA WAX SUBSTITUTE.* As a substitute for Carnauba wax, Concord Chemical Co. has developed Parwax. Physical and chemical characteristics similar to Carnauba, gloss readings are higher. For use in carbon paper, solvent polishes, and other wax products.

40 • *ACONITIC ACID.* A tribasic unsaturated acid for use in preparing esters, resin, plasticizers, etc. Made by the C. P. Hall Co. Data on physical properties.

41 • *NEW MONOMERS.* American Monomer Corp. in commercial production of ethylene glycol dimethacrylate and dially maleate for polyesters, copolymerization, rubber chemicals, coatings, and pharmaceuticals.

FOR FREE DATA →→→

Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18
19	20	21	22	23	30	31	32	33	34	35	36	37	38	39	40	41
45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61

PLEASE TYPE OR PRINT

Name _____ Position _____

Company _____

Address _____

City _____ Zone _____ State _____

BULLETINS

45 • **ALLOY STEEL TUBING.** A bulletin of condensed data on microstructure, critical points, effect of alloy elements, forging, machining, welding and thermal treatment of alloy steel tubing. Covers low carbon grades for mechanical uses. Babcock & Wilcox Tube Co.

46 • **PIPE LINE STRAINERS.** A bulletin of several types of pipe line strainers for all purposes, ranging in sizes from ⅛ to 36 in. Manual from the J. A. Zurn Mfg. Co. Contains information on selecting types and sizes of strainers for specific applications, and the effect of flow rate, screen loading, viscosity of fluid on pressure drop.

47 • **METERING PUMPS.** A 16-page catalog with specifications and technical data on a line of Maisch metering pumps. Issued by the Mechanical Products Corp. of Chicago, it is used for dispensing industrial and biological fluids. Includes sterile solutions. Stainless steel and pure carbon types. Quickly demounted and sterilized. Variety of outputs.

48 • **GENERAL PURPOSE PUMPS.** An Allis-Chalmers bulletin on grease-lubricated pedestal-mounted general purpose pumps. Gives construction details. Pumps available in capacities to 2500 gals./min. and heads to 550 ft. Illustrated, shows construction details, gives dimensions, and other specifications.

49 • **CONTINUOUS GRINDING.** Patterson Foundry & Machine Co. with a bulletin on ball, tube, and rod mills. Features continuous grinding for materials as fine as 10 μ or as coarse as 4 mesh. Illustrated, charts show size, weight, linings, ball charge, speed, power, etc. Well illustrated, each feature and construction detail separately described.

50 • **DYNEL WORK CLOTHES.** A bulletin on ChemKlos made of Dynel. Resistant to corrosive chemicals, available in the form of shirts, trousers, and coveralls. Easily cleaned, not harmed by commercial dry cleaning. Mine Safety Appliances Co.

51 • **FLEXIBLE PLASTIC TUBING.** For laboratory and pilot plant use a data sheet describing Alanol flexible tubing formulations. Available in quantities from 50 to 10,000 ft. and sizes ranging from .12 in. to ½ in. I. D. Resistant to a large line of chemical, aging, and abrasive conditions. From Couse & Bolten Co.

52 • **ABSOLUTE AIR FILTER.** For removing dust, smoke, fumes, etc., the Cambridge Corp. offers to industry an air filter originally developed for A.E.C. Filters are being produced in five capacities from 15 to 850 cu.ft./min. Will stop particles below 3/10 μ in size. High efficiency, light and compact.

53 • **OIL AND GREASE SEALS.** For the engineer that designs and chooses oil and grease seals for bearings, Garlock Packing Co. has just issued a 100-page catalog describing and illustrating all types made by it. Complete data, illustrations showing how mounted, how applied. Covers mechanical pressure seals for rotary shafts also.

54 • **NEUCLEONICS CATALOG.** A new 108-page catalog containing full information on Tracerlab's line of radioactivity equipment, tagged chemicals and consulting services.

55 • **DORR THICKENERS.** A catalog in color, which reviews the major types of Dorr thickeners with text, drawings, photographs and size ranges. It includes also control devices, special designs and a description of Dorr's engineering service. Well illustrated with pictures from industry and flow charts.

56 • **AMPCO ALLOYS.** A bulletin of information on aluminum bronze alloys by Ampco Metal, Inc. Includes corrosion-erosion resistance and cavitation-pitting data along with physical and chemical properties of various aluminum bronze alloys. Covers corrosion-resistant centrifugal pumps, plug valves, pipe, tube, tube fittings, tube sheet, etc.

57 • **AIRBORNE CONVEYING.** Airborne Conveyor Corp. has a portable air conveyor of suction or vacuum type for the transfer of powdered and granulated materials. Designed to fill machine supply hoppers, etc. Uses a flexible hose to convey material to a receiver located above the machine hopper to be serviced. Supplementary equipment and various capacities are described.

58 • **THERMOMETERS.** A specification sheet describing Brown indicating and recording thermometers. Construction and engineering details. Covers single-record, indicating, and two-record thermometers. Ranges available from −125 to +1000° F. Thermometer bulb styles are illustrated with construction details of fittings that are used.

59 • **JET PUMPS.** Penberthy Injector Co. describes in considerable detail Penberthy pumps, steam or air-operated. Bulletin gives capacities, suction lift, discharge head for various steam pressures and suction water temperatures. Data chart also covers list price, performance factors. Other sections show typical arrangements and application for installation of jets.

60 • **ROTAMETERS.** An engineering booklet from Brooks Rotameter Co. on flow meters. Covers rotameters for research and pilot plants, armored and control instruments, etc.

61 • **VACUUM PROCESSING SYSTEMS.** A catalog describing, with specifications, vacuum equipment used in industrial processing. Covers vacuum drying, rotary vacuum dryers, shelf dryers, freeze-drying, impregnators, metallizing, vacuum extraction and solvent recovering, etc. Also description of microvac pumps, vacuum gages, drum dryers, water stills, etc. F. J. Stokes Machine Co.

Postage Will Be Paid by Addressee

No Postage Stamp Necessary If Mailed in the United States

BUSINESS REPLY CARD

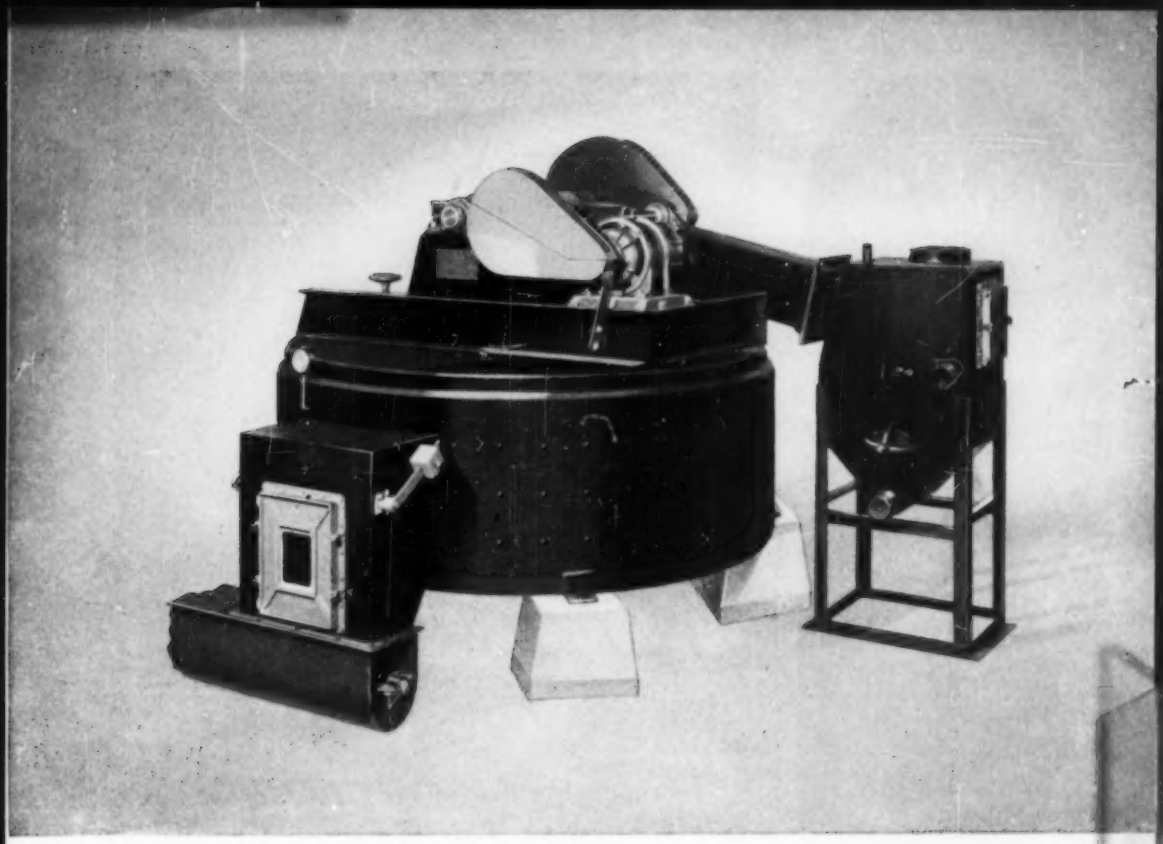
First Class Permit No. 48890, Sec. 34.9, P. L. & R., New York, N. Y.

Chemical Engineering Progress

120 East 41st Street

New York 17,

New York



Standard steam jacketed batch dryers

BARTLETT-SNOW STEAM JACKETED BATCH DRYERS are ideally used for drying small lots of various chemical salts, wood flour, tankage and similar materials.

Standard low cost style A dryers consist of a short vertical cylinder about 30 inches high with flat top and bottom. The top is closed, and is provided with a vapor outlet fan and charging door. The sides and bottom are steam jacketed in accordance with A.S.M.E. codes for steam pressures up to 100 p.s.i. in the jacket and 15 lbs. vacuum in the vessel. A two-armed cast steel sweep, keyed to the bottom of a center shaft, agitates the charge to prevent localized overheating and discharges the material through a door in the side after drying has been completed. Power requirement ranges from 5 to 15 HP depending upon the size and weight of the batch. Standard drive arrangements include; tight pulley, silent chain, V-belt or a heavy duty four speed transmission. Three standard sizes, with drying chambers 6', 8', and 10' in diameter, and capacities of about 1200, 3000, and 6000 pounds per charge, can usually be shipped promptly.

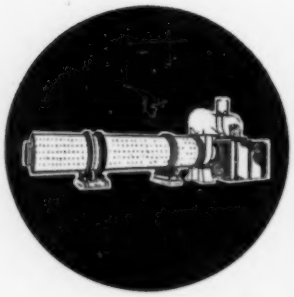
Send for a copy of Bulletin No. 89. It describes the scope of our service in detail, and let the Bartlett-Snow heat processing engineers work with you on your next drying, cooling, or calcining problem. The C. O. Bartlett & Snow Company, Cleveland 5, Ohio. Engineering representatives in New York, Baltimore, Detroit and Chicago.

BARTLETT-SNOW
CLEVELAND 5, OHIO

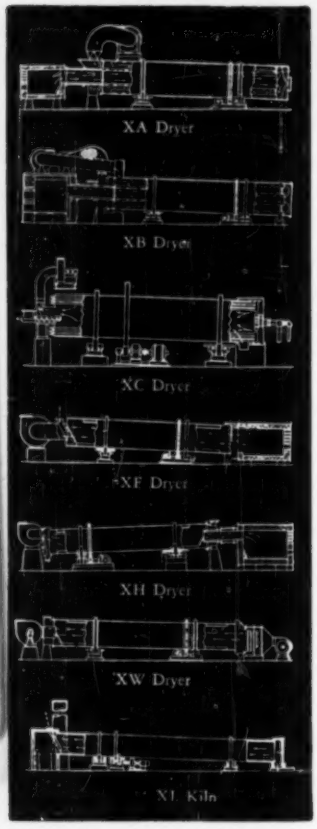
DRYERS • COOLERS • CALCINERS • KILNS

Designing and Contracting Engineers

COMPLETE MATERIAL HANDLING EQUIPMENT FOR ANY REQUIREMENT

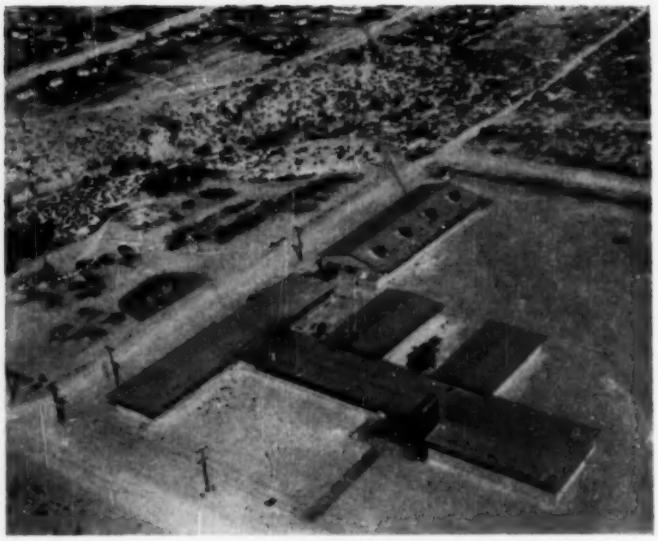


Ruggles-Coles
ROTARY DRYERS
in 7 types . . .



Write Hardinge for Bulletin 16-D-40 which describes the entire line of Ruggles-Coles Rotary Dryers, Kilns and Coolers.

HARDINGE
COMPANY, INCORPORATED
YORK, PENNSYLVANIA—240 Arch St. Main Office and Works
NEW YORK 17 • SAN FRANCISCO 11 • CHICAGO 6 • HIBBING, MINN. • TORONTO 1
122 E. 42nd St. 24 California St. 205 W. Wacker Dr. 2016 First Ave. 200 Bay St.



INFILCO'S RESEARCH BUILDING AT TUCSON

A new research and executive headquarters building was recently opened by Infilco at Tucson, Ariz. The $600,000 building, according to announcement by P. N. Engel, president, will house Infilco's engineering, research, and development divisions, as well as the home sales and executive offices. Set on seven and one-half acre plot, the new plant includes 40,000 sq. ft. of floor space.

NEWS

(*Continued from page 32*)

PRODUCTION OF NIACIN TO BE INCREASED

A new unit with a capacity in excess of one million pounds annually of niacin will begin operations next month, at the Cherokee plant of Merck & Co., Inc., near Danville, Pa. Niacin is a vitamin used in the enrichment of breakfast foods, and in animal feedstuffs.

The manufacture of niacin heretofore has depended upon coal-tar raw materials, now in short supply because of Government defense requirements. The Danville unit will employ a synthetic process using materials which are almost limitless in supply.

NUCLEAR SCHOOL OFFERS SCHOLARSHIP

The Oak Ridge Institute of Nuclear Studies is now receiving applications for Atomic Energy Commission graduate fellowships in radiological physics for the 1952-53 school year. The fellowships are awarded for study at two training centers: one at the University of Rochester in cooperation with Brookhaven National Laboratory, and the other at Vanderbilt University in cooperation with Oak Ridge National Laboratory. The final three months of the fellowship will be spent at the national laboratory. Appointments are made for one year for specialized training in radiological physics.

The annual basic stipend is $1500. An additional $500 is allowed for a wife and $250 for each of two dependent children, making a maximum stipend of $2500 annually. University tuition and fees will be paid by the Oak Ridge Institute of Nuclear Studies.

Applicants must hold an undergraduate degree, preferably with a major in physics, chemistry or engineering.

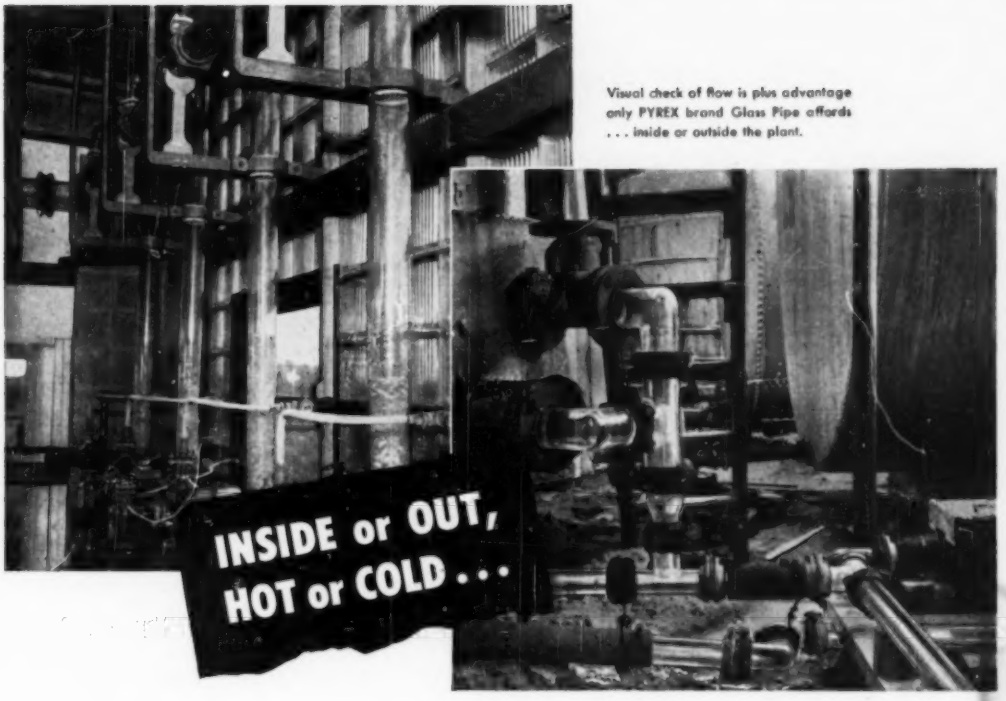
Application blanks and additional information may be obtained from the University Relations Division, Oak Ridge Institute of Nuclear Studies, P.O. Box 117, Oak Ridge, Tenn.

CHILE PLANS REFINERY

M. W. Kellogg Co., refinery and chemical engineer-contractors of New York were awarded a contract by Empresa Nacional Del Petroleo last month for the $10,000,000 refinery to be located at a site about ten miles north of Valparaiso in Chile.

Construction will begin under the direction of Kellogg Pan American Corp., in about a year. The refinery, a complete 20,000 bbl./day plant is the first in Chile.

Process facilities in the combination unit comprise crude oil distillation, treating equipment for sulfur removal from fuel gas, liquefied petroleum gases and gasoline, etc.



Visual check of flow is plus advantage only PYREX brand Glass Pipe affords . . . inside or outside the plant.

PYREX brand Glass Pipe *"Can Take It"*

If you believe that you must "baby" PYREX brand "DOUBLE-TOUGH" glass pipe, here are some facts that may surprise you. In use now for about 25 years, PYREX pipe has proved its dependability both inside and outside the plant (in all kinds of weather). The photographs above show typical installations . . . and this pipe has been in use for a long time.

Naturally, you can't throw glass pipe around or hit it with a hammer. But with reasonable care, it has always proved a profitable investment. PYREX brand glass pipe has a very low expansion coefficient. That's why it will take temperature shock . . . why it stands up in cold weather even with hot liquids flowing through it! And there is nothing better from the standpoint of corrosion resistance—it handles anything except hydrofluoric acid.

Physically strong to start with, PYREX brand glass pipe is now made with tempered ends—we call it "DOUBLE-TOUGH." The fittings, elbows, tees, reducers, crosses, etc., are also tempered. This treatment makes PYREX pipe better than ever before. With the current shortage of many corrosion-resistant materials, take a new look at PYREX Piping. It's available without priority and at reasonable cost. Corning's Piping Distributors can help you with layout and installation. Better get the full story. Use the coupon.

CORNING GLASS WORKS
CORNING, NEW YORK
Corning means research in Glass

1851 • 100 YEARS OF MAKING GLASS BETTER AND MORE USEFUL • 1951
Technical Products Division: Laboratory Glassware, Signalware, Glass Pipe, Gauge Glasses, Lightingware, Optical Glass, Glass Components

CORNING GLASS WORKS, Dept. EP-12, Corning, N. Y.
Send me your new Pyrex brand Glass Pipe Catalog.

NAME_____
COMPANY_____
ADDRESS_____
CITY_____ ZONE____ STATE_____

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before January 15, 1952, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Allen, Louis N., Jr., *Short Hills, N. J.*
Arnett, Earl F., *Lenox, Mass.*
Borg, E. Leonard, *Naugatuck, Conn.*
Brauning, John F., *Glen Ellyn, Ill.*
Bronson, George E., *So. Amboy, N. J.*
Davis, F. A., *Toronto, Ont., Canada*
Drew, Robert D., *Wenonah, N. J.*
Dykstra, Dewey I., *Pasadena, Tex.*
Eastman, N. S., *Charleston, W. Va.*
Elliott, Martin A., *Pittsburgh, Pa.*
Ferris, Theodore V., *Arlington, Mass.*
Fort, W. R., *Sayreville, N. J.*
Goldstein, Sidney, *Philadelphia, Pa.*
Hafslund, Earl R., *Lewiston, N. Y.*
Haney, Roy E. D., *Westfield, N. J.*
Heines, Philip, *Highland Park, N. J.*
Langdon, William M., *Chicago, Ill.*
Linak, Thomas R., *Louisville, Ky.*
Lux, John H., *Pittsfield, Mass.*
Marsik, Ferdinand V., *River Edge, N. J.*
Montes, Gustavo E., *Baton Rouge, La.*
Nikitin, Alexander A., *College Park, Ga.*
Perry, Eli, *Springfield, Mass.*
Rambo, Marvin L., *Fishkill, N. Y.*
Ross, Nestor J., *Rochester, N. Y.*
Schiller, James C., *Baytown, Tex.*
Somerset, Donald E., *Baltimore, Md.*
Storm, A. Paul, *Lyndalia, Del.*
Suhr, Henry B., *Trona, Calif.*
Thomas, George W., *Cloquet, Minn.*
Todaro, Casper A., *Mt. Prospect, Ill.*
Towse, Charles F., *Glendale, Mo.*
Udy, Murray C., *Columbus, Ohio*
Winters, Charles E., *Oak Ridge, Tenn.*
Wynn, Hugh, *Sayreville, N. J.*
Zinn, Eli, *Terre Haute, Ind.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

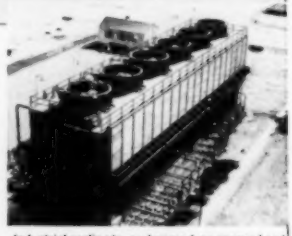
Detman, Roger, *So. Pasadena, Calif.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Abath, Walter F., *Wilmington, Del.*
Armenante, George A., *Great Notch, N. J.*
Bailey, Ernest John, *Turtle Creek, Pa.*
Barry, Robert Edward, *New York, N. Y.*
Bartlett, F. Leslie, *Wellington, Kan.*
Bass, James E., *Lawrenceburg, Ky.*
Bauknecht, Robert H., *Charleston, W. Va.*
Beard, James H., *Beaumont, Tex.*
Beckler, David Z., *Washington, D. C.*
Berry, Richard M., *Denver, Col.*
Biggs, Robert Dale, *Ann Arbor, Mich.*
Blickley, John F., *Niagara Falls, N. Y.*
Bohrer, Byron B., *Niagara Falls, N. Y.*
Breeden, Harold G., *Charleston, W. Va.*
Bunn, Lloyd T., *Orange, Tex.*
Burton, Joe M., *Bartlesville, Okla.*
Burton, Charles W., *LaMarque, Tex.*
Byerly, T. Edward, *Baltimore, Md.*
Calby, Joseph W., Jr., *Philadelphia, Pa.*
Cerelli, Victor, Jr., *Cliffside Park, N. J.*
Christian, Ronald R., *McKees Rock, Pa.*
Coffee, Ralph E., *Berkeley, Mo.*
Colletta, Victor Joseph, *West New York, N. J.*
Couture, M. J., *Charleston, W. Va.*
Crocker, Hilbert W., *Richland, Wash.*
Damasco, Frank S. *Cumberland, Md.*
Dietrich, Wendell F., *New York, N. Y.*
Doelp, Louis C., Jr., *Ridley Park, Pa.*
Donaldson, D. J., *Watsonville, Calif.*
Eagle, Raymond S., *Hillside, N. J.*
Erickson, James W., *Baton Rouge, La.*
Fader, Bruce A., *Chicago, Ill.*
Fields, Stanley R., *Richland, Wash.*
Fox, Alan J., *Beaver Falls, Pa.*
Goodman, Eli I., *Upton, N. Y.*
Graebert, Richard E., *Oak Ridge, Tenn.*
Haas, Paul A., *Oak Ridge, Tenn.*
Halsey, Brenton S., *Newport News, Va.*
Harris, T. R., *St. Louis, Mo.*
Henze, William K., *Hingham, Mass.*
Holback, John P., *Yonkers, N. Y.*
Holsen, James N., *St. Louis, Mo.*
Hornig, Robert G., *Akron, Ohio*
Howell, Kimbark, *Wilmington, Del.*
Ingalls, David P., *Bradford, Mass.*
Journeay, Glen E., *Angleton, Tex.*
Katz, John C., *Nashville, Tenn.*
Kern, Peter J., Jr., *Cleveland, Ohio*
Kile, Otho, Jr., *Homewood, Ill.*
Kircos, Paul, *Detroit, Mich.*
Knudson, Donald M., *Charleston, W. Va.*
Kobata, Harold T., *Gardena, Calif.*

(Continued on page 48)

It's a Pritchard Quality Tower . . .
It's Getting the Job Done More Efficiently . . .
More Economically!



Industrial cooling tower designed, engineered and constructed by J. F. Pritchard & Co.

You can always depend on Pritchard Quality Cooling Towers to do the job more efficiently . . . and at greater savings. Pritchard Towers are guaranteed to meet your peak loads as well as normal requirements because they're *adequately* sized and *thoroughly* engineered. Manufactured of highest quality materials for longer life, Pritchard Cooling Towers give you trouble-free service that cuts maintenance and repair costs. You save more water, too . . . up to 99% over former wasteful methods. Let Pritchard skill and experience go to work for you on your next cooling tower job!

Write for Bulletins

Gas & Air Treating
Specialized Heat Exchangers
Cooling Towers

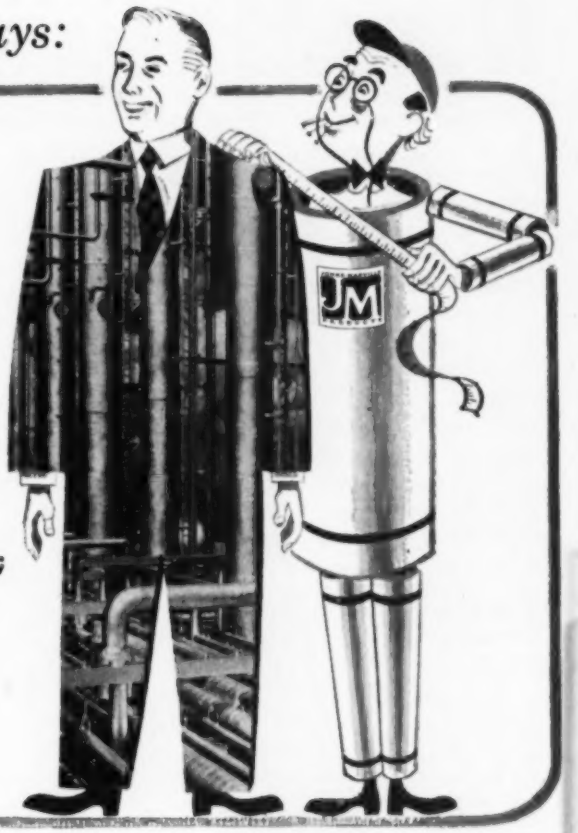
J. F. Pritchard & Co.
EQUIPMENT DIVISION
Dept. No. 158 908 Grand Ave. Kansas City 6, Mo.

District Offices: CHICAGO • HOUSTON • NEW YORK • PITTSBURGH
TULSA • ST. LOUIS • Representatives in Principal Cities from Coast to Coast

Mr. Insulation says:

"Buying insulation is like buying a suit of clothes:

—the better the materials; the more expert the tailoring, the better your investment"



Just as no one cloth can be used for every suit of clothes, there is no one raw material that can serve as the ideal insulator for every industrial insulation job.

For this reason, Johns-Manville manufactures a wide variety of industrial insulations—of asbestos and other raw materials—each of which is designed for a special purpose. These insulations span the entire range of temperatures from 400 F below zero to 3000 F above.

But, again, there is much more to the story of insulations than their manufacture. In order to get the greatest return from your investment in them, they must be expertly engineered to the job, and then skillfully applied.

Johns-Manville makes available to you the service of experienced insulation engineers, and highly skilled mechanics for the proper application of Johns-Manville insulations.

If you are contemplating an insulation installation for your plant, it will pay you to look into this Johns-Manville insulation service. For further information just write Johns-Manville, Box 290, New York 16, N. Y.

Johns-Manville *first in* **INSULATIONS**

FOR EXACTING TECHNICAL APPLICATIONS

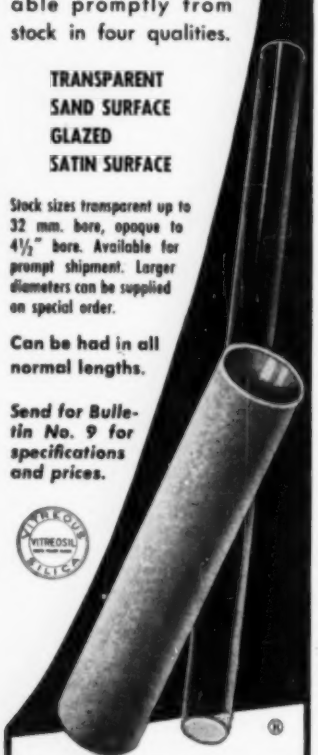
VITREOSIL* (vitreous silica) tubing possesses many characteristics you seek. A few of its properties are: Chemical and catalytic inertness. Usefulness up to 1000°C and under extreme thermal shock. Homogeneity and freedom from metallic impurities. Unusual electrical resistivity. Best ultra-violet transmission (in transmission quality). VITREOSIL tubing available promptly from stock in four qualities.

TRANSPARENT
SAND SURFACE
GLAZED
SATIN SURFACE

Stock sizes transparent up to 32 mm. bore, opaque to 4½" bore. Available for prompt shipment. Larger diameters can be supplied on special order.

Can be had in all normal lengths.

Send for Bulletin No. 9 for specifications and prices.



THE THERMAL SYNDICATE, LTD.
14 BIXLEY HEATH
LYNBROOK, N. Y.

SECRETARY'S REPORT

S. L. TYLER

The Executive Committee of the Institute met at the Institute Offices Nov. 7. The Minutes of the Executive Committee meeting of Oct. 12 were approved as well as the Treasurer's report and bills for the month.

All those applicants for membership whose names appeared in Chemical Engineering Progress for October, 1951, were elected to the grades of membership as indicated.

H. M. Merker was appointed representative of the Institute to attend the inauguration of Harlan H. Hatcher, president of the University of Michigan, Nov. 27.

Six resignations from membership were accepted.

Gouq-Jen Su was appointed counselor of the student chapter at the University of Rochester to succeed O. E. Dwyer.

The following men were appointed to serve on the Membership Committee at the request of C. G. Kirkbride, chairman: A. J. Miller, representing the Detroit Section, and J. Hoyt Chaloud, representing the Cincinnati, Ohio, Engineers Club.

Elbert E. Moore has returned from active service in the Armed Forces and therefore his participating membership has been reinstated by removal of his name from the Suspense List.

Several other matters of importance to the Institute were discussed at length but no actions were taken.

The Chemical Engineering Education Projects Committee of the Institute has just completed a list of the staff members in 98 chemical engineering departments in the United States, and Canada, for the school year, 1951-52. Copies of this list are available at the Secretary's Office at 25 cents each and distribution is limited to members of the Institute.

CANDIDATES FOR MEMBERSHIP

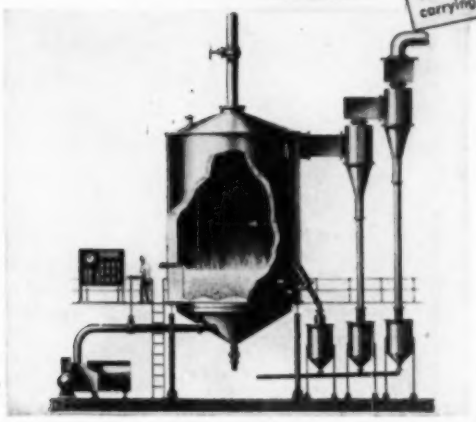
(*Continued from page 46*)

Kurz, Martin G., *Brooklyn, N. Y.*
LaMar, John R., *Terre Haute, Ind.*
Langenhagen, Charles F. Jr., *Wilmington, Del.*
LeCates, Perry B., Jr., *Baton Rouge, La.*
Leet, Harold A., *Elkton, Va.*
Longland, George M., Jr., *Algonquin, Ill.*
Lukas, Herbert A., *Milwaukee, Wis.*
MacCorkle, Arthur Harry, *Cheltenham, Pa.*
Malone, Albert V., *Merriam, Kans.*
Mays, James P., *Wilmington, Del.*
McBride, John A., *Phillips, Tex.*
McCracken, Philip G., *Terre Haute, Ind.*
McLaren, Donald B., *So. Charleston, W. Va.*
Meyers, James R., *Pittsburgh, Pa.*
Milich, Walter, *Lyndora, Pa.*
Miller, James A., *Bound Brook, N. J.*
Miller, Kenneth G., *New York, N. Y.*
Molaison, Warren J., *Wilmington, Del.*
Mosby, Cleveland Gay, Jr., *Buckhannon, W. Va.*
Myers, John H., III, *Bloomfield, N. J.*
Newman, John A., *Rochester, N. Y.*
Newton, Charles L., *Columbus, Ohio*
Parisi, George I., *Newark, N. J.*
Peterson, Ralph C., *Cincinnati, Ohio*
Pettengill, Kenneth H., *Cambridge, Mass.*
Pontius, Philip W., *St. Albans, W. Va.*
Pyle, Philip H., *Tacoma, Wash.*
Robertson, Arthur W., *St. Louis, Mo.*
Rodekohr, Edward S., *Marshalltcn, Del.*
Rolke, William A., *Terre Haute, Ind.*
Roming, Charles, *Bradford, Pa.*
Roy, Tuhin K., *Elizabeth, N. J.*
Rydalch, Floyd H., *Monterey Park, Calif.*
Sachs, Stuart M., *Brooklyn, N. Y.*
Sarvadi, George, Jr., *Mayfield Hghts., Ohio*
Schimmel, William W., *Brooklyn, N. Y.*
Seiden, Nathan, *Brooklyn, N. Y.*
Serenbetz, Harold E., *Wilmington, Del.*
Shuff, Thomas J., *Philadelphia, Pa.*
Sparks, Calvin E., *Texas City, Tex.*
Spatz, Dale, *Charleston, W. Va.*
Spencer, F. J., *Springfield, Mass.*
Stater, Robert G., *Evanston, Ill.*
Stege, Calvin B., *Rochester, N. Y.*
Stewart, William E., *Portsmouth, Ohio*
Thorson, Paul E., *Minneapolis, Minn.*
Towers, Edmund, *Detroit, Mich.*
Troutman, Harvey A., *University, Miss.*
Vekkos, Elias L., *Army Chemical Center, Md.*
Voelkerding, Henry A., *Bloomsburg, Pa.*
Von Hohenleiten, Ralph L., *Cleveland, Ohio*
Walen, Nicholas, *Pittsburgh, Pa.*
Walz, Richard, *Buffalo, N. Y.*
Wang, Philip I. C., *Louisville, Ky.*
Weber, James M., *Bartlesville, Okla.*
Wheelock, Thomas D., *Charleston, W. Va.*
Wilson, Neil G., *Houston, Tex.*
Wright, Kenneth W., Jr., *Terre Haute, Ind.*
Woods, William C. A., *San Bernardino, Calif.*
Zagula, Ben Aloysius, *Bound Brook, N. J.*

Can you use

14-15% SO_2 GAS from PYRITE

Dorrco FluoSolids* will produce it . . . at lower investment and operating costs than conventional roasters.


FACTS ON
SO_2 PRODUCTION
BY FLUOSOLIDS
GAS STRENGTH will average 14-15% SO_2 dry basis from pyrite carrying 48-50% sulphur.
GAS CLEANING EQUIPMENT is smaller because of smaller gas volumes.
FEED can be relatively coarse . . . flotation concentrate to 35 mesh—jig or table concentrate to 14 mesh.
MINIMUM MAINTENANCE . . . no moving parts exposed to high temperature—long refractory life.
NO SCALING . . . temperature accurately controlled below fusion point.
NO EXTRANEOUS FUEL is needed once fluidized bed is up to calcining temperature.
PROCESS SHUT-DOWNS of two or three days present no roasting problem.
COMPLETE INSTRUMENTATION eliminates the personal factor in operation.

● Sulphuric acid manufacturers and all users of sulphur dioxide faced with a shortage of elemental sulphur will find in FluoSolids an economically feasible means of tapping sulphides as an alternate source of SO_2. Utilizing the principle of fluidization, The Dorrco FluoSolids System is a distinct departure from conventional roasters. It brings SO_2 production from those sources down to a reasonable investment and operating cost level.

Its economy, simplicity and ease of operation are indicated by the facts above. For more detailed information write to The Dorr Company, Stamford, Conn., or in Canada, The Dorr Company, 80 Richmond Street West, Toronto 1.

*FluoSolids is a trademark of The Dorr Company, Reg. U. S. Pat. Off.

Better Yields TODAY in most laboratory devices!

DORRCO

DORR

WORLD-WIDE RESEARCH · ENGINEERING · EQUIPMENT

THE DORR COMPANY · ENGINEERS · STAMFORD, CONN.
Associated Companies and Representatives in the principal cities of the world

– at its Best where Corrosion is Worst

The recognized quality of Knight-Ware Chemical Stoneware is the result of selected raw materials, careful forming by master craftsmen and controlled processing. But, more than that, Knight-Ware's quality results from experience — the "know-how" gained in almost half a century of making Laboratory and Processing chemical equipment. A few of the outstanding features to be found in Knight-Ware include:

Flexibility of Design — Special equipment can be handmade in many shapes or sizes at relatively low cost.

One-Piece Construction—No joints or seams to come open. Even intricately baffled pieces can be made in one seamless, jointless piece.

No Maintenance — No seams, coatings or linings to maintain or replace.

100% Resistance — Not just surface resistance but corrosion proof clear through. It will pay you to investigate the advantages of KNIGHT-WARE. Write for a Knight-Ware Catalog specifying in your letter type of equipment in which you are interested.

Knight-Ware Chemical Equipment

Sinks	Suction Filters
Table Troughs	Jars
Acid Lines	Towers
Fume Ducts	Valves
Tanks	Berl Saddles
Kettles	Coolers
Sumps	Pulsometers

Special Shapes to Order

MAURICE A. KNIGHT
712 Kelly Ave., Akron 9, O.
Acid and Alkali-proof Chemical Equipment

LOCAL SECTION NEWS

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Atlanta, Ga., Atlanta Biltmore Hotel, Mar. 16-19, 1952.

Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.

Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept 11-13, 1952.

Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

SYMPOSIA

New Types of Equipment for Use in Process Industries

Chairman: D. M. Considine, Market Extension Div., Ind. Div., Minneapolis-Honeywell Regulator Co., 7th and Grange Sts., Philadelphia, Pa.

Meeting—Atlanta, Ga.

Market Research

Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

Meeting—Atlanta, Ga.

Vacuum Engineering

Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Meeting—French Lick, Ind.

Distribution of Chemicals

Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.

Meeting—Chicago, Ill.

Human Relations

Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering

Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.

Meeting—Cleveland, Ohio.

Filtration

Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.

Chemical Engineering in Hydrometallurgy

Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.

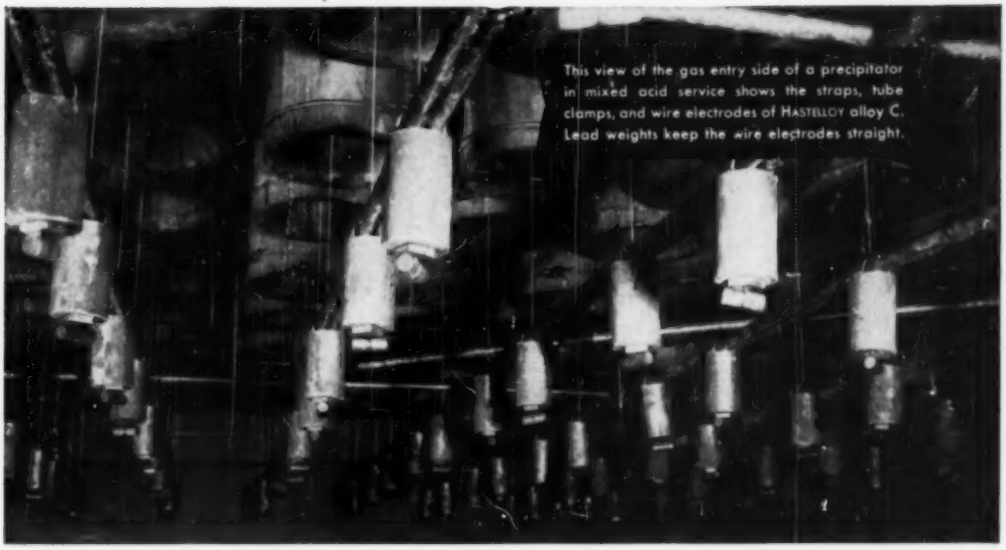
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics

Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

(*More Local Section News on page* 54)



This view of the gas entry side of a precipitator in mixed acid service shows the straps, tube clamps, and wire electrodes of HASTELLOY alloy C. Lead weights keep the wire electrodes straight.

Precipitators Improved...

WITH NICKEL-ALLOY ELECTRODES

Electrostatic precipitators for removing corrosive liquids and solid particles from industrial process gases give better and longer service, without maintenance, when HASTELLOY alloy wire is used for electrodes. The alloy has excellent mechanical strength (130,000 psi) and is not attacked by the corrosive agents. This combination of properties makes it possible to use electrodes that are only 0.073 in. in diameter. The effective diameter of the lead-covered wire formerly used in most units was more than 0.500 inch. The smaller cross-section of the HASTELLOY alloy wire permits the use of higher voltages with a more uniform corona pattern.

HASTELLOY alloy C electrodes have been installed in mist precipitators where hydrochloric, sulphuric, sulphurous, and mixed acids were present. A recent check on an installation in an acid plant showed that the alloy C wires experienced no weight loss after a year's operation. Lead-covered steel wires, on the other hand, lasted an average of 11 months with electrode failure at least once a week.

For information on wrought forms of HASTELLOY alloy, write for the booklet, "HAYNES Wrought Alloys Price List."

HAYNES TRADE-MARK *alloys*

"Haynes" and "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
UCC
General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

A.I.Ch.E. AND THE STUDENT CHAPTER

L. P. SCOVILLE

Vice-President, Jefferson Chemical Company, Inc., New York

Past Chairman, New York Section, A.I.Ch.E.

THE New York Section is aware of the importance to the Institute of its student chapters. Many of their present members will, in the course of time, be charged with the responsibility of furthering the Institute's program. Just as the Army recognizes its noncommissioned cadres as a vital integrating force in any group action, so must the local sections' present officers be made aware that the Institute's future strength lies in the active interest and continued loyalty of its student chapter members. The man who has come up through the ranks really "knows the ropes," and is of far greater value to the group than one who has become associated as an expedient, or to enjoy a temporary prestige.

The record shows that about ten per cent of student chapter graduates apply for membership in the national organization. It will be admitted that this is not a good showing, and that there is indicated a need for an active program on the part of the local sections to evoke a quality of interest among the student chapter members which will endure beyond university life.

One way to increase the interest of the student chapters in the national organization is to make them realize that the A.I.Ch.E. can and does help them. Apparently, this can best be done through the local sections, since there are sections near most of the major universities and certainly, aid to the student chapter must largely rest upon personal associations. In view of this, the New York Section has embarked during the past school year on a trial program to give aid to the student chapter at Pratt Institute with the thought that if the program proved to be advantageous, the assistance could then be extended to the five other student chapters in the New York metropolitan area. This program may be subdivided into four phases:

a. Aid to the student chapter in obtaining speakers.
b. Vocational guidance for the seniors.
c. Aid to student chapter groups by awarding prizes and by taking an interest in their group conferences.
d. Encouraging active participation of Junior members in the activities of the local section.

EDITOR'S NOTE

Continuing the brief articles on Institute activities published in "C.E.P.," the accompanying article by L. P. Scoville points up some of the things which have been done by the New York Section for the students in the metropolitan area, and some of the plans envisaged by this section for the coming school year. Here is a constructive program for encouraging students in their professional development and for advising local sections of their vital role in the progress of the student. Other articles in this series on Institute activities were run in the September issue, page 48, and in the March issue, page 46.

The New York Section appointed a committee, early in 1951, to aid the local sections in obtaining speakers from industry for their meetings. As an initial step, the section launched a cooperative program with the student chapter at Pratt Institute. J. A. Hufnagel of the New York Section was appointed chairman of this committee and worked closely with Charles Lando, program chairman of Pratt Institute's student chapter. Though only two speakers were obtained through the services of the New York Section—it was rather late in the school year—one covering the subject of the fermentation industry and the other the food industry, the results were quite gratifying, for the student chapter showed a lively interest in hearing speakers from industry who discussed these subjects with authority. The cooperation from representatives of industry can be explained by the fact that A.I.Ch.E. is a national body of high professional standing, and its request to a company for a speaker receives prompt consideration from top management. The topic treatment and method of presentation are formulated by A.I.Ch.E. for the students' advantage. Effort is made to select a young speaker, yet one who has the necessary experience and qualifications. Such an individual, it is believed, is best able to present the subject from the students' standpoint.

It is anticipated that during the next school year the New York Section will furnish this service to all six student chapters in the New York metropolitan area. Speakers will be obtained on any subject desired by the students, or, if found advisable, the various program chairmen will be given counsel and guidance on subjects for different programs.

At that same time, another committee of the New York Section was formed, with W. D. Kohlins as chairman, to aid the student chapters in vocational guidance. The purpose of this committee is to arrange interviews for groups from the graduating class with men in industry specializing in various branches of management, such as research and development, engineering, sales and production. Each group consists of five or six graduating chemical engineers. These men call at the office of the counselor from industry and discuss the prospective activities of a graduate chemical engineer in the particular field. The students understand that these are not employment interviews but entirely for the purpose of developing information about the type of work which would be done by the graduate in that particular field, and the future possibilities for his professional advancement. Since these groups are small, the students are led to have a feeling of informality and are able to ask questions without restraint. Also, talking to the men in industry gives the students a sense of "getting it straight from the horse's mouth," and they have more confidence in information thus developed than in that received from faculty members.

Here again, it was thought that the New York Section should start out in a small way and not try to take on all comers at the very beginning. For this reason, a liaison was established through Prof. Richard F. Shaffer of Pratt Institute, and several exploratory conferences were held with the students by men from industry. The results were

extremely encouraging. As anticipated, students found the interviews both interesting and constructive. Accordingly, it is planned to broaden this portion of the program, also, to include all six student chapters during the coming school year. It was found an advantage to bring into the conferences a man who has worked in a given branch of industry for only two or three years since leaving college. Such younger men were able to talk to the graduating students in the language of youth. Experience with these initial conferences, however, suggests that they be held in the fall of the year rather than in the spring, since seniors then would have an opportunity to give more serious consideration to the work they wish to pursue and thus have their minds more definitely fixed at the time of their subsequent employment interviews.

The New York Section has, for the past several years, given two prizes, one for the best graduate paper and one for the best undergraduate paper given at the metropolitan student chapter conference which is held every spring. This practice is tangible evidence to the student chapters that A.I.Ch.E. is interested in encouraging their activities.

Although these cited steps will increase the students' interest in the national organization, their increasing interest alone is not enough to insure growth in the number of those working actively in the Institute. It is necessary also to sustain the interest of the Junior members in the program of the national organization. This can best be done by appealing to their special interests and encouraging them to be active in their local sections—an aim which requires continued planning and which should not be left to chance. Too often, the local sections are dominated by Active members and, as a result, the programs and activities rather discourage the interest of the Junior members. The New York Section has recognized this problem and is urging Junior members to take an active role in committees and, in addition, is promoting the election of Junior members to its executive committee. A plan under consideration is to amend the bylaws to form a specific membership on the executive committee which must be held by a Junior member, in order that representation of the Junior members may be assured. This Junior member would be charged with the responsibility of seeing that the wants and desires of the younger members of A.I.Ch.E. are given a voice in planning the activities of the section.

Such are the methods adopted to insure a steady influx of new members to the Institute—members who are young and alive, and who are thoroughly indoctrinated with the spirit of progress and the advancement of the profession.

(The End)

A REGULAR SERVICE OF THE **COOPER ALLOY** FOUNDRY CO., HILLSIDE, N. J.

CA Technical Topics

ALLOY TYPE FA-20*

Norman S. Mott
Chief Chemist and Metallurgist

Although FA-20* was originally developed for use in hot sulphuric acid solutions, its high resistance in various media as well as its superior physical properties has increased its popularity to the point where it is presently being supplied by our foundry for valves, pump units, pipe fittings, and a variety of cast shapes used in the chemical, textile, paper, plastic and food industries.

FA-20 offers superior resistance, as compared with 18-8-SMO, in hot strong solutions of calcium or magnesium chlorides and aluminum sulphate; in dilute solutions of tin, zinc, iron or mercury chlorides at room and slightly elevated temperatures; and in cold dilute solutions of sodium or calcium hypochlorite. It is also superior in sulphur dioxide solutions or sprays, in dry chlorine gas at ordinary temperatures, wet hydrogen sulphide gas, boiling sodium or potassium hydroxide solutions of over 30% concentration, acid sludges up to 200° F., and in hot vinegar and salt solutions.

In sulphuric acid its use is required when the concentration is over 40% at room temperature, 10% at 175° F. or 0.75 % at boiling; and it is satisfactory in all concentrations of this acid at temperatures up to 175° F., and up to 40% of concentration at boiling. It is recommended for boiling phosphoric acid when the concentration exceeds 10%, and for hydrofluoric acid of less than 10% or over 60% strength at room temperatures, although fair service may be had at all concentrations.

FA-20 is not recommended for use with wet chlorine gas or other wet halogens; chloroacetic acid; hot strong solutions of copper, iron or mercury chlorides; or with molten sodium or potassium hydroxides. It is satisfactory for service in nitric acid solutions, but for this use, it offers no superiority over 18-8 type alloy and does not justify the additional cost.

* Produced under Durimet patents.

Maximum properties at lowest cost are achieved when the alloy is cast to the following specifications:

Carbon	.07%	Max.
Chromium	20.00%	
Nickel	29.00%	
Copper	4.00%	
Molybdenum	3.50%	
Silicon	1.00%	
Manganese	1.00%	
Tensile Strength	75,000 psi	
Yield Point	45,000 psi	
Elongation 2"	40%	
Reduction in Area	45%	
Brinell	150	

The nickel content offers good resistance to sulphuric acid corrosion and maintains the copper in alloy solution, minimizing the possibility of its becoming a contaminant in corrosion. Chromium provides resistance to nitric acid and other oxidizing media, and together with the nickel supplies the excellent mechanical properties of the alloy. Molybdenum and copper provide for increased sulphuric acid corrosion resistance and the molybdenum also increases passivity and reduces the tendency to pitting. The low percentage of carbon is essential for resistance to intergranular corrosion attack. Silicon and manganese are incidental to the production of the alloy, and in the amounts present provide little influence on mechanical or corrosion resisting properties.

Available on request

Copies of this article printed on heavy stock convenient for filing are available. Address requests to Publicity Dept., The Cooper Alloy Foundry Co., Hillside, N. J.

COOPER ALLOY
Stainless Steel
VALVES · FITTINGS · CASTINGS

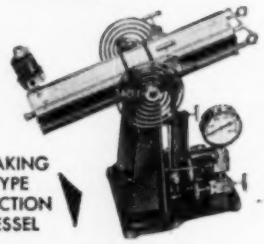
HIGH-PRESSURE REACTION VESSELS

• Various types, with or without shaking or stirring mechanisms, heating jackets, and removable corrosion-resistant liners.

Standard volumes, 43 ml. to 20 liters, for pressures up to 60,000 psi. and temperatures up to 800°F.

Vessels for continuous reactions can be built for pressures up to 100,000 psi. and temperatures up to 2500°F.

STIRRING TYPE REACTION VESSEL



SHAKING TYPE REACTION VESSEL

OTHER AMINCO SUPERPRESSURE PRODUCTS

Valves • Fittings • Tubing
Dead-weight Gages
Pumps • Compressors
Pilot Plants
Instruments

Write for Catalog 406-E

Superpressure Division
AMERICAN INSTRUMENT CO.
Silver Spring, Maryland

LOCAL SECTION NEWS

(*Continued from page* 50)

SOUTHERN CALIFORNIA

This Section's monthly dinner meeting was held jointly Nov. 8 with the following societies: A.S.M., A.I.M.E., A.S.C.E., A.I.E.E., A.S.M.E., N.A.C.E. The Southern California section of the A.S.T.M. was program sponsor, and more than 500 engineers were present to hear Frank LaQue, in charge corrosion engineering section, development and research division, International Nickel Co. Mr. LaQue has been concerned principally with corrosion of metals for the last 15 years and so was able to call on a wealth of experience for presentation of a version of his A.S.T.M. Edgar Marburg Lecture on corrosion.

Officers for this Section of A.I.Ch.E. for 1952 are as follows:

Chairman—F. J. Lockhart, Univ. of So. Calif.
Vice-Chairman—G. R. Lake, Union Oil Co.
Sec'y Treasurer—S. G. Sevougian, Dow Chemical; A. K. Brumbaugh, General Petroleum Co.
Executive Comm.—Senior Members—E. R. McCartney, Fluor Corp., Ltd., and W. F. Seyer, Univ. of Calif. at Los Angeles
Executive Comm.—Junior Members, P. G. Young, Ralph M. Parsons Co.; D. R. Stern, Western Electrochemical., and R. G. Ischinger, Univ. of So. Calif.
Representative to Los Angeles Engineering Council of Founder Societies—F. C. Brunner, C. F. Braun & Co.; H. J. Engebretsen, Midland Rubber Co.

Reported by Gale S. Peterson

BOSTON

Ichthyologists

In the Campus Room of the M.I.T. Graduate House, Nov. 2, William Weeks, a member of the New Boston Committee and a dean of freshmen at Harvard University, discussed how this committee was attempting to obtain better government in Boston.

Reported by R. Antonsen (Smelt)

ROCHESTER

The first meeting of the year was held Oct. 17, 1951, at Rundel Memorial Library.

A. Ackoff reported on the successful Rochester meeting of the A.I.Ch.E. held Sept. 16-19, 1951. A letter of thanks from Institute Executive Secretary Tyler was read. It was announced that the award for the best technical paper at the Rochester meeting went to Richard D. Boutros, of Mixing Equipment Co., Inc., for his paper, "Installation, Operation, and Maintenance of Fluid Mixing Equipment."

Carl Gath of Eastman Kodak Co. reported on his attendance at the Engineering Manpower Convocation sponsored by the Engineering Manpower Commission of E.J.C. in Pittsburgh, Pa., Sept. 28, 1951.

The speaker of the evening was A. W. Davison, director of research for Owens-Corning Fiberglas Co. His subject was, "Fiberglas, A New Engineering Material." His talk concerned its strength, sound absorption, insulation. He showed samples of different applications as a material of construction.

The meeting was preceded by a dinner in honor of Dr. Davison at Lorenzo's Restaurant. There were about 45 people at the dinner and about 75 at the meeting.

Reported by Irving Siller

WESTERN NEW YORK

Albert McIntosh, an economist and statistician for the Socony Vacuum Oil Co., spoke on the "World Oil Situation" at the Nov. 8 meeting. It was his belief that the free world would be drastically rationed if the Middle East reserves are lost to their use.

Reported by W. C. Greenwald

DETROIT

Donald Katz of the University of Michigan addressed this Section on "Heat Transfer in Finned Tubes and by Liquid Metals" before approximately 75 members who attended the dinner meeting at the Rackham Memorial Nov. 8. Professor Katz's talk covered recent and past comparative results including an economic evaluation of plain and finned tubes.

Prof. R. R. White was presented with the A.I.Ch.E. Award Certificate for excellent delivery of a paper at the Kansas City meeting.

Reported by Dwight Miller

TEXAS PANHANDLE

This Section met in Phillips, Tex., Oct. 18, 1951, to hear M. H. Leavenworth of Dow-Corning Corp., talk on "Recent Developments in the Field of Silicones." At the lecture and demonstration 72 were present.

Reported by H. W. Hennigan

TWIN CITY

Edgar Piret, professor of chemical engineering at the University of Minnesota, spoke at the October meeting of this Section on "Let's Look at Europe Today." The meeting was held at the Angus Hotel in St. Paul Oct. 24. Dr. Piret recently returned from a year's study at the University of Lyon in France under a Fulbright scholarship.

Reported by William M. Podas

PHILADELPHIA-WILMINGTON

The second meeting of the 1951-52 season was held at the Clubhouse Hotel, Chester, Pa., Nov. 13, 1951. The dinner was attended by 70 members and guests with approximately 130 present at the meeting that followed.

Officers elected for the 1952 season are as follows:

Chairman—A. P. Colburn, Univ. of Delaware
Vice-Chairman—Wm. E. Chalfant, Atlantic Refining Co.
Recording Secretary—T. A. Burtis, Houdry Process Corp.
Corresponding Secretary—Wm. E. Osborn, Atlantic Refining Co.
Treasurer—Wm. A. Bours, DuPont Co.
Assistant Treasurer—Harry Bolton, Philadelphia Quartz Co.
Executive Comm.—R. B. Chillas, Retired; J. Dart, Houdry Process Corp.; T. W. Tomkowit, DuPont Co.

The speaker for the evening was John M. Pearson, director, physical division of the research and development department, Sun Oil Co., Marcus Hook, Pa. He discussed "Methods of Discovering and Producing Crude Oil."

Reported by W. E. Osborn

TERRE HAUTE CHEMICAL ENGINEERS CLUB

Officers for the current year are:

Chairman.....A. C. Miller
Vice-Chairman.....R. M. McGhee
Secretary.....J. W. Bulls
Treasurer.....W. E. McCoy
Executive Comm...... B. J. Quinn
R. O'Ferrall
D. Thomson

O. E. Isenburg, B. F. Goodrich Chemical Co., spoke to 53 members and guests Oct. 23 on "Progress in Vinyl Resins—What's Ahead."

Reported by James W. Bulls

WESTERN MASSACHUSETTS

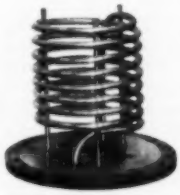
At the November meeting, Warren K. Lewis, professor of chemical engineering at M.I.T., spoke on "Chemical Engineering as a Profession." For the October meeting, a symposium, "Extrusion," was arranged by John M. Chamberlin of Monsanto's plastics division in Springfield. Approximately 125 members and guests were in attendance. The guest speakers were James Bailey, director of research at Plax, Inc., and H. E. Buecken, manager of the plastic machine division of National Rubber Machine Co. New extruder designs, applications, operating techniques, and control factors were discussed.

Reported by R. H. Marks

Protect It with Fansteel Tantalum Equipment!

The whole pie represents the selling price of the merchantable product which you manufacture. The big portion of the pie represents the raw material costs, plus your processing costs of the raw material. The little piece of the pie is the important one . . . it's your profit!

As raw material costs continue to increase, it is often difficult to increase selling prices in proportion. This, of course, results in a smaller operating margin. And if this material, for which you pay more, is subject to corrosive attack, there is the problem of spoilage through contamination from corroded processing equipment. This makes the going really tough.



Tantalum steam coil for rapid heating of contents of agitated kettle.

USE TANTALUM WITH ECONOMY for most acid solutions, corrosive gasses or vapors; not with HF, alkalis or substances containing free SO3.

Write for informative bulletins on Tantalum Acid-Proof Equipment.

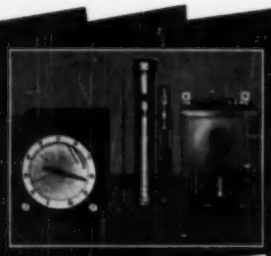
When considering all this, you will come to realize that the small additional investment you make in acid-proof tantalum equipment is a worth-while expenditure. Consult with Fansteel engineers on the possibility of using tantalum equipment in your operations. Fansteel Metallurgical Corporation, North Chicago, Ill., U.S.A.

AN INDUSTRY THAT SERVES INDUSTRIES

Fansteel

Acid Proof TANTALUM CHEMICAL PLANT EQUIPMENT

12404-C



GAGETRON Applied to Measurement of Catalyst Level

New industrial application of atomic energy employs radium and hydrogen tube. Catalyst level is measured by number of atomic impulses passing through the counter tube. The primary element is the GAGETRON.

The GAGETRON is manufactured under Graham Patent No. 2,565,963.

FREE! Safety Code for use of radium. Also GAGETRON Bulletin No. 149.

INSTRUMENTS, INC.
122 N. Madison Tulsa 6, Okla.

MARTINDALE PROTECTIVE MASKS

PLACE HEADBAND WELL UP AROUND HEAD TO KEEP FROM SLIPPING DOWN
PRESS NOSE TABS IN CLOSE AGAINST FACE TO HOLD PAD AGAINST THE NOSTRILS
PRESS EDGES OF FACE PLATE DOWN TO FIT FACE SNUGLY

Weigh less than ½ ounce

These light-weight aluminum masks provide protection against over 400 dusts such as wood, coal, lime, salt, cement, grain, rust, paper, textiles, some insecticides, paint spray from non-toxic paints, etc.

Pads can be changed in a few seconds. Only clean gauze touches the skin. Comfortable to wear. Workers like them.

Martindale Protective Masks...$3.30 ea.
No. 1 Refills (Standard weight) .02 ea.
No. 2 Refills (Heavyweight) .02½ ea.

Write for quantity discounts

MARTINDALE ELECTRIC CO.
1322 Hird Ave.,
CLEVELAND 7, OHIO

PITTSBURGH

William B. Gamble, manager of the Pittsburgh office of Price Waterhouse & Co., was the speaker at a dinner meeting Nov. 7 at the College Club. An overflow attendance heard Mr. Gamble explain "Elements of Corporate Finance and Financial Accounting."

The speaker traced the economic development cycle of a hypothetical chemical company, starting from initial organization to the final manufacturing and marketing operations.

On Jan. 9, 1952, at the Royal York Apts., Pittsburgh, V. F. Parry, chief, Fuel Technology Laboratories, U. S. Bureau of Mines, Denver, will discuss a process for the low temperature carbonization of lignite—a process developed at the Bureau's Denver laboratories.

Reported by H. L. Kellner

CHICAGO

Approximately 100 members and guests met at the Builders Club Nov. 7 for the second meeting of the season. The speaker was R. E. Meints, chief of design coordination of Argonne National Laboratory, who spoke on "Design Problems on an Atomic Energy Laboratory Site." The unusual architectural arrangements and the special ventilation and personnel handling requirements were explained and illustrated.

Reported by Thorpe Dresser

CENTRAL VIRGINIA

This Section held a dinner meeting at the Albemarle Hotel, Charlottesville, Va., Nov. 16, 1951. Thirty-five members and guests were present. The election of the following officers to serve for the year 1952 was announced.

Chairman.....S. A. Lamanna
Vice-Chairman.....O. L. Updike
Secretary-Treasurer...H. N. Fiaccone

Two moving pictures, "West Virginia and Its Natural Resources," and "Historic Virginia," were shown.

Reported by L. E. Poese

OKLAHOMA

This Section met recently at McKinley School in Bartlesville to hear J. J. Mikita, director of the petroleum laboratory of the Du Pont Co., talk on "Combustion Chamber Deposits and Engine Efficiency."

Mr. Mikita discussed the mechanism of formation of deposits in combustion chambers of automobile engines and pointed out the effect of these deposits on engine efficiency. Results of laboratory and road tests, shown on colored slides, indicated that increases in compression ratio and temperature due to the deposits were the main causes of "knock" increase under given conditions.

Mr. Mikita emphasized the point that increased engine performance could be accomplished through the cooperative efforts of petroleum refiners, engine designers and chemical producers.

Reported by H. M. Hawkins

BATON ROUGE

The second meeting of the fall season was held on Nov. 14, 1951, at which the guest speaker was Thomas H. Chilton, President of A.I.Ch.E., who addressed the group on "Why Is an Engineering Society?" This was an informative discussion of the aims and functions of engineering societies, and the services and accomplishments which can be realized by collaborative efforts of these societies.

The first fall dinner-meeting held Sept. 27, 1951, brought a record turnout attendance of 90. The guest speaker was E. Duer Reeves, executive vice-president of the Standard Oil Development Co., who discussed "Principles and Administration of Research and Development." He covered such topics as meaning of research and development; calculated risks and its place in the selection, control, and termination of research projects; and pilot plant administration.

The next meeting will be held on January 4, 1952, at which E. W. R. Steacie, vice-president of the National Research Council of Canada, will discuss "Reactions of Alkyl Radicals."

Reported by J. C. Fedoruk

MIDLAND

The first meeting of this (in formation) section was held Oct. 24, 1951, at the auditorium of the Dow Chemical Co., Midland, Mich. Eighty members and guests were present. After a talk by William I. Burt, Vice-President of A.I.Ch.E., on "The Chemical Engineering Profession and the Institute Today," a short business meeting was held. Chairman Noland Poffenberger introduced John W. Carey, vice-chairman, James Kapnicky, secretary-treasurer, and the following committee chairmen: Max Key, membership; Frank Landee, program; Raymond Duddleston, publicity. Mr. Poffenberger announced that the executive board would consist of Ralph Prescott and Ken Coulter. All the officers are with the Dow Chemical Co.

Reported by Raymond Duddleston

CHARLESTON

A meeting was held Oct. 16 at the Charleston Recreation Center at which 146 members and guests heard R. F. Romell of the Vulcan Copper and Supply Co. discuss "The Design of Bubble-Cap Distillation Trays." Mr. Romell described methods currently used in the design of distillation columns for the chemical industry and discussed details of arrangement and construction in dealing with certain problems encountered.

The first session of the course in distillation sponsored by the section was held Oct. 18 at the Charleston High School. E. H. TenEyck, of Du Pont's plant at Belle, W. Va., was the lecturer for the first two sessions.

Reported by G. K. S. Connolly

ST. LOUIS

A meeting was held Oct. 16, at the York Hotel, with Raymond R. Tucker, St. Louis director of public safety and head of Washington University's department of mechanical engineering, as featured speaker. Professor Tucker discussed the Civil Defense Organization in the St. Louis area in relationship to an atomic bomb attack and the steps necessary to correct the gaps in the defense structure.

This section's opening fall meeting was a Smoker held at Anheuser-Busch Inc. on Sept. 18, 1951.

Reported by A. T. Pickens

KANSAS CITY

The monthly dinner meeting of this Section was held Oct. 30 and was attended by about 50 members and guests. A symposium on waste disposal was presented. Speakers for the session were Charles Huntress of the Municipal Service Co., John Lamkin, Standard Oil Co., and Ralph Porges, Public Health Service.

Reported by I. E. Miller

MARYLAND

At the Nov. 13 meeting at Johns Hopkins University, Lt. Col. Fred Bellinger of the Army Chemical Corps spoke on "Development of Chemistry and Chemical Engineering in the United States."

At the Oct. 16 dinner-meeting 36 members attended. The speaker was L. W. Bass, vice-president of U. S. Industrial Chemicals, Inc., and a Past President of the Institute, who discussed "Increased Unity in the Engineering Profession."

Reported by Alan Beerbower

Lapp

AUTO-PNEUMATIC

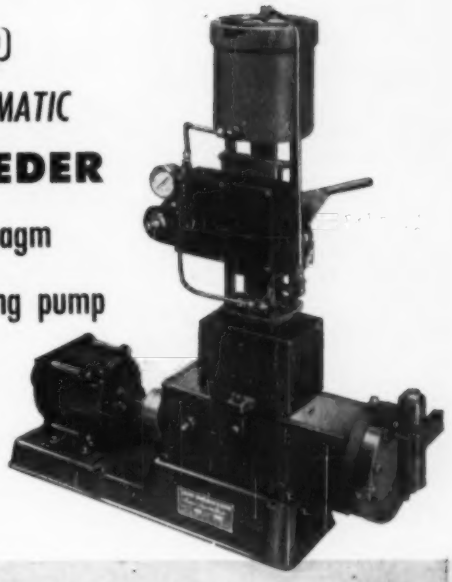
PULSAFEEDER

piston-diaphragm

chemical metering pump

with automatic

output control



For automatic metered pumping of corrosive or "hard-to-handle" chemicals, the Lapp Auto-Pneumatic Pulsafeeder offers new accuracy, efficiency and dependability. Applicable to all pneumatic or electro-pneumatic instrumentation, the Auto-Pneumatic Pulsafeeder provides automatic metering in response to variable flow, pH, temperature, liquid level, pressure, or other processing variables. The Pulsafeeder accomplishes this with a pump that operates at a constant pumping speed; variable flow results from variation only in piston stroke length, controlled by the pneumatic cylinder. In addition, through a manual ratio control, means is provided for accurate adjustment of output rate independent of instrument air pressure changes. And the Lapp Pulsafeeder is the positive displacement proportioning pump that operates without stuffing box or running seal. Its hydraulically-balanced diaphragm acts as a floating partition which isolates the chemical being pumped from pump parts—to protect against contamination of product or equipment. Entire mechanism inherently explosion-proof.

WRITE for complete description and specifications. Lapp Insulator Co., Inc., Process Equipment Division, 455 Maple St., LeRoy, N. Y.

Lapp

PROCESS EQUIPMENT

CHEMICAL PORCELAIN VALVES • PIPE • RASCHIG RINGS

PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

ANOTHER HORTON ALUMINUM TANK

REDUCING CORROSION for Hercules Powder

Hercules Powder Company recently installed the Horton aluminum tank shown above at its Parlin, N. J., plant to increase acid storage facilities. The three Horton aluminum tanks below have been used to store corrosive materials at Parlin for some time.

For quotations on tanks of solid, clad or lined corrosion-resistant metals, write our nearest office.

CHICAGO BRIDGE & IRON COMPANY

Atlanta 3	7131 Healey Bldg.
Birmingham 1	1940 North Fiftieth St.
Boston 10	1055—201 Devonshire St.
Chicago 4	2138 McCormick Bldg.
Cleveland 15	2232 Guildhall Bldg.
Detroit 26	1546 Lafayette Bldg.
Houston 2	2154 National Standard Bldg.
Los Angeles 17	1541 General Petroleum Bldg.
New York 6	3372—165 Broadway Bldg.
Philadelphia 3	1640—1700 Walnut Street Bldg.
Salt Lake City 4	860 West 17th South St.
San Francisco 4	1536—200 Bush St.
Seattle 1	1360 Henry Bldg.
Tulsa 3	1643 Hunt Bldg.
Washington 6, D. C.	1133 Cafritz Bldg.

Plants at BIRMINGHAM, CHICAGO, SALT LAKE CITY, and GREENVILLE, PA.

PEOPLE

H. L. Barnebey, associated with Blaw-Knox since 1939 after six years' production experience in the chemical industry, has severed his connection with that firm and is establishing his own business in Pittsburgh, Pa., in the selection, evaluation, and licensing of important processes. These include: location and selection of a process to answer a specific requirement; evaluation of a process for a particular purpose, or in comparison with other methods, to establish its present and future worth; promotion to industry, on a royalty basis, of chemical processes which have proved their worth by successful pilot plant operation or commercial use. Mr. Barnebey was graduated from Ohio State University with a degree in chemical engineering in 1933. With Blaw-Knox Mr. Barnebey served as manager of the process equipment department in one of the manufacturing divisions and later was in charge of sales promotion, advertising and the investigation of new processes for the chemical plants division.

Harry D. Irig is now vice-president in charge of research at the Allis-Chalmers Manufacturing Co., Milwaukee 1, Wis. He was formerly associated with the Globe Steel Tubes Co. in that city.

Max Leva, consulting engineer of Pittsburgh, Pa., has been engaged by the chemical engineering department at West Virginia University as visiting lecturer, part time. Mr. Leva was formerly with the United States Bureau of Mines, Pittsburgh, Pa.

John Sosnowski, who received his M.S. in chemical engineering this year from Rensselaer Polytechnic Institute, has joined the staff of the process division of the Standard Oil Development Co., Linden, N. J.

Alfred S. Jennings is now a chemical engineer in the atomic energy division of the Du Pont Co., Schenectady, N. Y. He recently received his B.S. degree from Washington University, St. Louis, Mo.

Charles A. Coghlan is now with the development research department of the Texas Co.'s Beacon Laboratories, Beacon, N. Y. Mr. Coghlan was formerly with the company's Port Arthur refinery, Port Arthur, Tex.

Earl W. Flosdorf, director of research and development at the F. J. Stokes Machine Co., Philadelphia, Pa., recently returned to the United States after delivering a speech on "Large-Scale Freeze-Drying as Currently Carried Out in the Western Hemisphere" at a congress on freezing and drying held in London, England, under the auspices of the Institute of Biology. Dr. Flosdorf is credited with a major part in the development of dried blood plasma. Following the London meeting, Dr. Flosdorf visited universities and companies in England, Switzerland, Liechtenstein, France and Italy, where he discussed the equipment used there.

Lewis W. Gleekman, assistant professor in chemical engineering at the University of Delaware, has been appointed chairman of the Committee for Young Engineering Teachers of the American Society for Engineering Education. He had taken part in the early conferences which led to the committee's establishment two years ago and has been a member of the committee for a year. Dr. Gleekman received his Ph.D. in chemical engineering from the State University of Iowa.

Earl F. Arnett has been appointed manufacturing engineer in the chemical division of General Electric's Coshocton, Ohio, plant of the division's laminated and insulating products department. He has been with the company since 1940, holding various positions until January of this year, when he was placed in charge of the chemical process development section, which assignment he held until his present promotion. Mr. Arnett was previously a chemical engineer for the Three Rivers Oil Refining Co. and the Standard Oil Co.

Marjorie W. Leigh has joined the process division of the Esso Laboratories, Linden, N. J. Miss Leigh received her B.S. in chemical engineering at Cornell University in 1951.

James S. Wolff has been appointed Washington, D. C., representative of the B. F. Goodrich Chemical Co., Cleveland, Ohio. Mr. Wolff, a graduate of Carnegie Institute of Technology, joined the company in 1946 and has been its technical representaive in Chicago since 1947.

Judd W. Healy, chemical engineer in the Standard Oil Company research laboratory at Whiting, Ind., has been promoted to group leader at the company's Wood River, Ill., laboratory. Mr. Healy, who received his M.S. degree in chemical engineering from the Massachusetts Institute of Technology, joined Standard in 1947.

Donald W. Collier has been appointed director of research for Thomas A. Edison, Inc., West Orange, N. J., and will have charge of the company's Central Research Laboratories. Dr. Collier, who received his Ph.D. degree from Princeton University, was formerly with the Sharples Corp., Philadelphia, Pa., where he was head of chemical research and process development.

Alf Erickson is now a chemical engineering consultant in Fort Lauderdale, Fla. He received his B.S. in chemical engineering from the University of Wisconsin and was previously associated with the Atlas Powder Co., Wilmington, Del.

Andrew F. Bertuzzi is now a graduate student at the University of Kansas. He was formerly associated with the Phillips Petroleum Co., Bartlesville, Okla.

Akbar F. Brinsmade, formerly with International Industrial Consultants, in Venezuela, is now process engineer for the Fluor Corp., Ltd., Los Angeles, Calif.

Eric Jenett is now a process engineer for Brown & Root, Inc., Houston, Tex. He was formerly associated with the Eastman Corp.

E. Gordon Foster, formerly with the Du Pont Co. is now an assistant professor at the University of Louisville.

Frederick Fussman, formerly associated with the Blaw-Knox Construction Co., Pittsburgh, is now a process engineer for the Chemical Construction Corp., New York, N. Y.

Edward T. Bartram is now with the Du Pont Co., Wilmington, Del. He was formerly with Hollingsworth & Whitney Paper Manufacturers, Waterville, Me.

Richard N. Auguston is a chemical engineer at the Mound Laboratory of the Monsanto Chemical Co., Miamisburg, Ohio. He was previously a graduate student at Iowa State College.

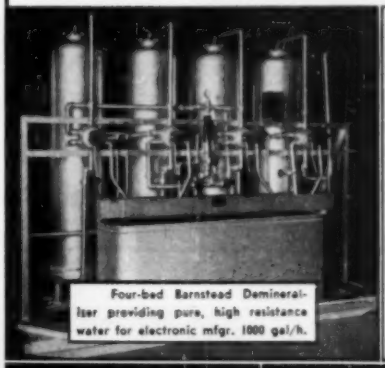
John F. Heiss, formerly of the University of Pittsburgh, is now a project engineer for the Westvaco chemical division of the Food Machinery & Chemical Corp., Pocatello, Idaho.

Carlisle W. Gilbert is now a chemical engineer for the Blaw-Knox Construction Co., Pittsburgh, Pa. Mr. Gilbert, who received his B.S. from Washington University, was formerly a process engineer for the Firestone Tire & Rubber Co., Pottstown, Pa.

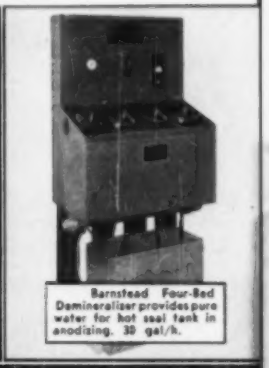
BARNSTEAD DEMINERALIZERS

PROVIDE LOW-COST PURE WATER

for • Electroplating • Anodizing
• Photographic Solutions
• Salt-free Rinse Water • Silvering
And Hundreds of Other Applications



Four-bed Barnstead Demineralizer providing pure, high resistance water for electronic mfgr. 1000 gal/h.



Barnstead Four-Bed Demineralizer provides pure water for hot seal tank in anodizing. 30 gal/h.

Two-bed Barnstead Demineralizer. Used in large automotive plant. 1000 gal/h.

Four-bed Barnstead Demineralizer produces pure, sparkling-clear rinse water for pharmaceutical plant. 200 gal/h.

Selection of the best size and type of demineralizer for your operation depends on the nature of your raw water supply, flow rate needed, daily demand, and degree of purity required. Send a sample of your water to our Laboratory and Barnstead Engineers will perform the necessary analysis without obligation.

PROMPT DELIVERIES *WRITE FOR FREE CATALOG*

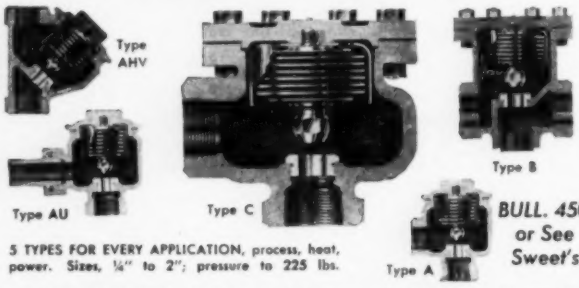
Barnstead
STILL & STERILIZER CO.
82 Lanesville Terrace, Forest Hills, Boston 31, Mass.

In This Plant Nicholson Traps

SAVED 10% IN STEAM COSTS

Chief Engineer H. F. D. stated, after Nicholsons replaced mechanical traps in his plant: "Saving in steam waste cut our fuel cost at least 10%. Yet application temperatures were up 30°-40°. And relief of all air binding effected faster warm-up."

Operate on lowest temperature differential; 2 to 6 times average drainage capacity; maximum air venting. For other advanced Nicholson features send for Bulletin 450.



5 TYPES FOR EVERY APPLICATION, process, heat, power. Sizes, ¼" to 2"; pressure to 225 lbs.

BULL. 450 or See Sweet's

W. H. NICHOLSON & CO., 214 Oregon St., Wilkes-Barre, Pa.

Sales and Engineering Offices in 53 Principal Cities

HIGH VACUUM PUMPS REQUIRE CLEAN OIL

VACUUM PUMP USERS INSTALL HILCO OIL RECLAIMER SYSTEMS TO KEEP LUBRICATING AND SEALING OILS FREE OF SOLIDS, . . GUMS, . . WATER AND GASES

THE HILCO OIL RECLAIMER IS COMPLETELY AUTOMATIC

FOR BETTER VACUUM AND REDUCED VACUUM PUMP MAINTENANCE COSTS INVESTIGATE THE HILCO OIL RECLAIMER

★ WRITE FOR FREE LITERATURE . . A RECOMMENDATION WILL BE MADE . . NO OBLIGATION ON YOUR PART.

THE HILLIARD CORP.
144 W. 4th St., ELMIRA, N. Y.

IN CANADA—UPTON-BRADEEN-JAMES LTD. 950 BAY ST., TORONTO—3484 PARK AVE., MONTREAL

Corrosion Proof Construction Materials

Corrosion Proof CEMENTS
A complete line of sulfur base, resin base, plastic and silicate cements. Write for bulletin 5-1.

Corrosion Proof FLOORS
Permanent floors for chemical process, steel, textile, food industries, etc. Write for bulletin 3-1.

Corrosion Proof LININGS
Corrosion proof linings based on natural rubber, neoprene, saran, polyethylene, etc. Write for bulletin 4-1.

PROTECTIVE COATINGS
Time-tested coatings based on vinyls, styrene, neoprene, saran, phenolics, furfuryl alcohol polymers, etc. Write for bulletin 7-1.

Rely on Atlas' years of experience and recognized leadership to help solve your problems. Write 34 Walnut Street, Mertztown, Pa.

Over a half century of service

Atlas
MINERAL PRODUCTS COMPANY
MERTZTOWN, PA. HOUSTON, TEXAS

PEOPLE

(*Continued from page 59*)

J. P. Moser has been named general manager of Lever Brothers Company's manufacturing division in New York. Mr. Moser received his B.S. degree in chemical engineering from Tufts College and has been affiliated with Lever Brothers for 26 years. For the past year and a half he has been manufacturing manager.

Raymond W. Winkler, who received his M.S. and Ph.D. in chemical engineering from Washington University, has joined the development division of the Standard Oil Development Co., Linden, N. J.

Charles A. Wolbach, Jr., has joined the Equipment Development Co., Inc., Montclair, N. J., as sales engineer of filter fabrics and filtration equipment. Mr. Wolbach, who received his B.S. in chemical engineering from Lehigh University, was formerly research chemist and development engineer in the titanium division of the National Lead Co., South Amboy, N. J.

Theodore Vermeulen has been promoted to full professor and **Charles R. Wilke** has been made associate professor of chemical engineering at the University of California. Mr. Vermeulen received his Ph.D. from the University of California and Mr. Wilke received his M.S. from the State College of Washington and his Ph.D. from the University of Wisconsin.

John C. Hunt has joined the staff of the Standard Oil Development Co., Linden, N. J. Dr. Hunt received his M.S. in chemical engineering from the University of Michigan and his Ph.D. from the University of Washington.

R. E. Whitson, formerly with Aluminum Research Labs., E. St. Louis, Ill., is now chief chemical engineer for the Aluminum Ore Co., Bauxite, Ark.

Mack Gilkeson, formerly research assistant at the University of Michigan's Engineering Research Institute, is now assistant professor at Tulane University of Louisiana, New Orleans, La.

R. Cameron Hammersley, now a chemical engineer for American Cyanamid Co., North Plainfield, N. J., was previously an instructor in the University of Wisconsin's chemical engineering department.

PEOPLE

Homer Kiewig

Russell B. Crowell

Homer Kiewig has been appointed manager of the central division, and Russell B. Crowell has been named manager of the western division, two newly created divisions in the production and engineering department of Commercial Solvents Corp., New York. Mr. Kiewig joined Commercial Solvents in 1935 and was successively superintendent of the derivatives and penicillin plants, and engineer on the Peoria nitroparaffin plant. In 1944 he was sent to England to aid the Distillers Co., Ltd., in constructing a penicillin plant. He has been chief engineer of CSC's engineering division since 1945. Mr. Crowell was formerly manager of the Agnew plant. He came with Commercial Solvents in 1933 when the company acquired the Rossville Alcohol Co., where he had been employed for thirteen years.

THOMAS, TRUSTEE CARNEGIE CORPORATION

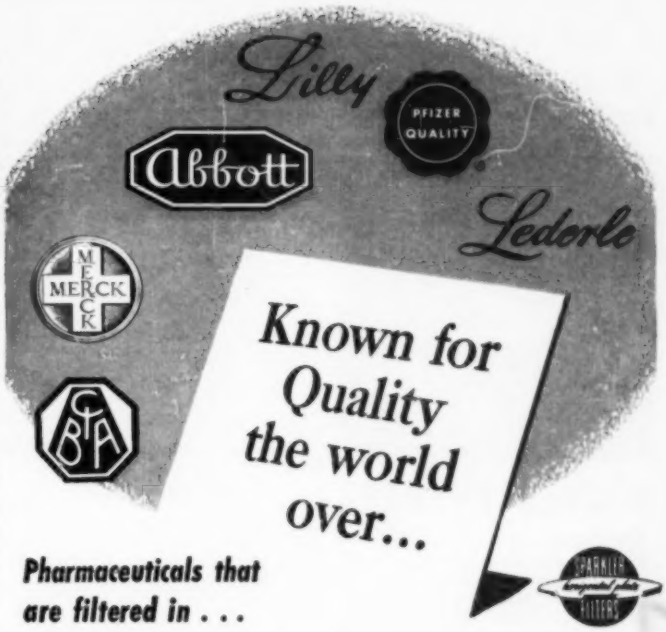
Charles Allen Thomas, president of the Monsanto Chemical Co., St. Louis, Mo., has been elected a trustee of the Carnegie Corporation of New York.

Dr. Thomas was a coauthor of "A Report on the International Control of Atomic Energy (the Acheson-Lilienthal Report) which outlined a plan for the international control of atomic energy and was prepared for the Secretary of State's Committee on Atomic Energy. He also served as chairman of the Scientific Manpower Advisory Committee of the National Security Resources Board which issued last January a report on the utilization of scientific manpower for defense.

Starting out as a research chemist, Dr. Thomas was associated with General Motors Research Corp. and Ethyl Gasoline Corp., successively, before organizing the Thomas & Hochwalt Laboratories in Dayton, Ohio, to do industrial research. When the laboratories were acquired by Monsanto Chemical Co. in 1936, Dr. Thomas became Monsanto's central research director, and in 1945, he was elected vice-president and technical director. Two years later he became executive vice-president.

Robert V. Jelinek has joined the development division of the Standard Oil Development Co., Linden, N. J. Dr. Jelinek did both his undergraduate work and graduate work at Columbia University, receiving his Ph.D. in 1951.

(More About People on page 64)



Pharmaceuticals that are filtered in . . .

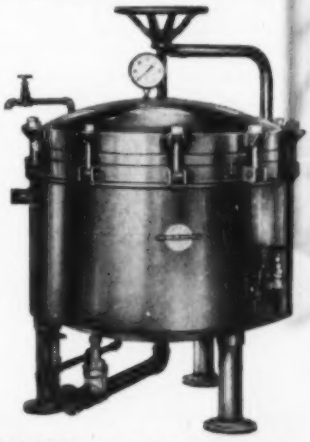
SPARKLER FILTERS

Each company whose trade-mark is shown above has, for many years, produced medicinals meeting the highest attainable standards. As a result, their reputations are based on what amounts to a public trust that products bearing these trade-marks can be used with complete confidence. To protect their positions of leadership, these manufacturers employ every conceivable safeguard to assure unvarying purity.

We are proud, therefore, that Sparkler filters have been chosen by such outstanding companies, and that we have been associated with them for so long — because we earnestly believe that Sparkler filters have contributed to their success.

Sparkler design and construction lend themselves perfectly to sanitation and superior filtration because Sparkler originated and perfected the horizontal plate principle; the scavenger plate to assure complete recovery of product; the use of cartridge-type elements that minimize down-time and simplify cleaning; the flexibility that permits use of all types of media; and many other distinctive advantages.

If quality and efficiency at economical operating costs are *your* foremost considerations, you will want to know more about Sparkler filters. Write for your copy of the Sparkler catalog today. For engineering assistance, write Mr. Eric Anderson.



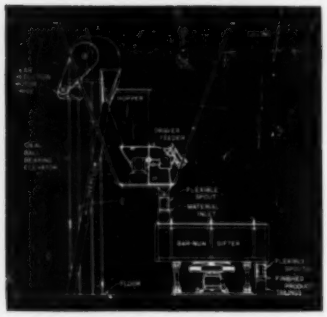
Representatives in all principal cities

SPARKLER MANUFACTURING COMPANY Mundelein, Illinois

European Plant: Herengracht 568, Amsterdam, Holland

Manufacturers of fine filtration equipment for more than a quarter of a century

Speed-up Production.. Regulate Material Flow To Production Equipment..Install..



DRAVER FEEDERS

THE extremely *precise* DRAVER "Micro-Master" Feeder keeps even stubborn, dry material coming at the *right* rate to get maximum production without overloading . . . ends the danger of choke-ups, wasted power, inefficient operation and undue wear on Sifters, Grinders, Elevators or Conveyors. For more accurate, economical feeding either to individual production units or to Continuous Mixing Systems, get all the information on the DRAVER line. Made in over 100 models with capacities ranging from minute quantities to 1000 cubic feet per hour. The coupon, mailed today, will quickly bring you all the facts.

TEAR OUT.. PASTE ON LETTER-HEAD AND MAIL TODAY!

B. F. Gump Co., 1311 S. Cicero Ave., Chicago 50

Gentlemen: Please send me descriptive literature and complete information on the GUMP-Built Equipment indicated below.

- ☐ **BAR-NUN ROTARY SIFTERS** for grading, scalping or sifting dry materials.
- ☐ **DRAVER FEEDERS** for accurate, dependable volume percentage feeding.
- ☐ **DRAVER MASTER** Continuous Mixing Systems for accurate, efficient, uniform mixing.
- ☐ **VIBROX PACKERS** for packing down dry materials in bags, drums, barrels.
- ☐ **AUTOMATIC NET WEIGHERS** for accurately weighing from 3 oz. to 75 lbs. for packaging or processing.

B.F.Gump Co.

Engineers and Manufacturers Since 1872

1311 SOUTH CICERO AVENUE
CHICAGO 50, ILLINOIS

CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at $15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 20th of the month preceding the issue in which it is to appear.

SITUATIONS OPEN

EXECUTIVE—With minimum of ten years' experience in operation of heavy chemical plants. Salary, $15,000 a year. Location, New Mexico. Box 2-12.

CHEMICAL ENGINEERS, RESEARCH AND DEVELOPMENT—Large nationally known Eastern manufacturer of soaps and detergents has excellent new opportunities for B.S., M.S. and Doctorate graduate in chemical engineering. Two to ten years' experience plus level of educational background will qualify you for these interesting, diversified, career positions. This is an expanding versatile organization offering generous salary ranges, stability of employment, and liberal employee benefits. Send us a résumé of your work history, education and salary requirements. Box 3-12.

ENGINEERS

Permanent positions with excellent opportunities in New York office.

Chemical Engineers

Recent graduates or graduates having experience with process design with major oil refiner, chemical company or contractor for process investigations and job engineering.

Chemical Engineer

(Research)

B.S. or M.S. for process and economic evaluations and assisting in transfer of research developments to commercial production. Strong technical background essential.

Mechanical Engineer

Graduate with four or five years' heavy industrial, chemical or oil refining company experience for diversified activities in plant layout, process piping, power plant design and process equipment layout. Knowledge of pumps, compressors and plant maintenance problems desirable.

Submit resumé

Jefferson Chemical Company, Inc.

711 5th Ave., New York 22, N. Y.

Pl. 9-3900

ALBERTA

CANADIAN CHEMICALS COMPANY, LTD.

Edmonton, Alberta, Canada

Experienced Canadian Personnel Only

Chemical engineers for production supervisory positions in Petro-chemical and Cellulose Acetate divisions.

Experienced men for production supervisory positions in Yarn and Staple Fibre Division.

Reply with personal background, education, experience, and salary expected. Personal interviews will be arranged. All replies will be held confidential.

Address Replies to

Personnel Superintendent

Celanese Corporation of America

Box 148

Bishop, Texas

VISCOSE ENGINEER

National organization seeks capable graduate engineer with minimum 5 years' experience in viscose rayon manufacture. Headquarters New York. Salary high.

Send complete resumé including age and salary data.

Box CP 463, 221 W. 41 St., N. Y. C. 18

OPPORTUNITIES FOR EXPERIENCED TECHNICAL PERSONNEL IN ATOMIC ENERGY INSTALLATIONS AT

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Electromagnetic Separation Plant
Oak Ridge, Tennessee

Gaseous Diffusion Plants
Oak Ridge, Tennessee & Paducah, Ky.

ENGINEERS

DESIGN - DRAFTING — chemical plants, structures, piping, valves, utilities, alterations.

LABORATORY — research and development.

POWER—design, testing, construction of large electrical power generation and distribution installations.

MACHINE DESIGN — jigs, fixtures, gadgets, remote control equipment.

PROCESS—chemical process and equipment design, vacuum or high-pressure systems, pilot plant and production operation.

CONSTRUCTION — plant design, specifications, sub-contractor liaison.

SAFETY — pressure vessel inspection and fire protection.

NUCLEAR REACTORS — design, development, construction, testing.

INSTRUMENTATION — design development and industrial application of electronic and pneumatic instruments.

INDUSTRIAL AIR - CONDITIONING AND REFRIGERATION—design of plant systems.

CHEMISTS, PHYSICISTS, METALLURGISTS

Research, development, and production in nuclear technology, gaseous diffusion, and related fields.

Minimum educational requirement —B.S. degree, or its equivalent.

Salary commensurate with training and experience.

Give experience, education, age, references, personal history, salary received and salary expected.

Central Technical Personnel Office
Carbide and Carbon Chemicals Company
a Division of
UNION CARBIDE AND CARBON CORPORATION
Post Office Box P
Oak Ridge, Tennessee

ASSISTANT EDITOR—Young chemical engineer needed for general editorial work on engineering magazine in the chemical field. News, meetings, feature assignments, etc. Reply giving education, present work, salary expected, experience, etc. Box 1-12.

CHEMICAL ENGINEER—Desired for associate research professor in accredited Southern college. Ph.D. preferably with research, industrial and teaching experience. Also interested in an assistant professor with Ph.D. or degree candidate. Box 4-12.

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER — Experienced in handling design and erection for the complete plant as project engineer. Bulk of experience in detergents, pharmaceuticals, and organic chemicals. Seeking position as chief engineer. New York area. Box 5-12.

PROCESS ENGINEER—Twelve years in process development, supervision of construction, operation and personnel. Economic studies, evaluation of processes and patents. Desire process engineering or economic evaluation. Box 6-12.

CHEMICAL ENGINEER SHORTAGE?—Would like contact with employer who really needs a man with twelve years of diversified research and development experience. Box 7-12.

CHEMICAL ENGINEER—27, family, veteran. Three years' research experience in high pressure organic syntheses (carbon monoxide, acetylene, ethylene oxide). Desire production position or development of high pressure processes from laboratory scale to plant stage. Box 8-12.

CHEMICAL ENGINEER-ATTORNEY — B.S., M.S.; LL.B. in February. Seek a position with a consultant, construction or production firm in a legal capacity. Broad engineering background with experience in research and development. Prefer Middle West, but not essential. Box 9-12.

CHEMICAL ENGINEER—M.S., Univ. of Washington, 1949. Two years' experience in petroleum and refinery engineering. Desire position with future in aggressive oil or chemical company. Single, 28. Box 10-12.

CHEMICAL ENGINEER—34, family, B.Ch.E. Seven years' diversified experience process and product development, pilot plant design and operation, production trouble-shooting, economic evaluations, technical reports. Variety of chemicals. Presently employed. Seek responsible position development, engineering, production. Box 11-12.

PROJECT ENGINEER—B.S.Ch.E., 33, family. Design of organic chemical and antibiotic plants. Estimates, instrumentation and utilities. New York area. Salary $8500. Box 12-12.

PROCESS ENGINEERING SUPERVISOR — Chem. Eng., McGill. Eleven years' experience. Your tough job is my meat. Petrochemical and petroleum refining work. Now employed at $12,000 per year. Canadian, and proud of it. Box 13-12.

CHEMICAL ENGINEER—Univ. of Florida, 1948, honor graduate, 27, single. Desire position as sales representative for chemical or equipment manufacturer in Mexico and/or Southwest U. S. Three years' residence on Mexican border; fair Spanish. Currently in direct sales. Junior member A.I.M.E. Box 14-12.

REFINERY ENGINEER—B.S.Ch.E. Five years' experience furnace and equipment design; operation with technical and engineering sections of major midwest refinery. Desire position in responsible capacity with small organization; similar work or pilot plant and development. Box 15-12.

ENGINEERING MANAGER — Twenty years progressive design, construction and administration in chemical process and mechanical equipment fields. Dr.Eng.Sc. Functional building and economy programs for utilities, maintenance, and product recovery. Background: petroleum, food, detergent, and drug industries. Married, family; prefer N. Y. C. $20,000/yr. Available early 1952. Box 16-12.

Foam's a Fraud...Kill it With

DOW CORNING ANTIFOAM A

To get the most out of your process equipment, add a trace of Dow Corning Antifoam A and use the space you've been wasting on foam. You'll process most of your most violent foamers, even under vacuum or continuous heat, without waste or hazardous overflow.

That's because Dow Corning Antifoam A kills foam faster and in a wider variety of foamers than any other material known. Practically odorless, tasteless and non-toxic, it is safe to use in food and drugs at concentrations up to 10 parts per million—many times the concentrations normally required.

That kind of efficiency makes Dow Corning Antifoam A the most economical as well as the most versatile defoamer available.

See for Yourself

Send Coupon Today for Your FREE SAMPLE

DOW CORNING SILICONES

Dow Corning Corporation,
Dept. AS-12*
Midland, Michigan

Please send full information and a free sample of Dow Corning Antifoam A.

Name_____
Company_____
Address_____
City_____ Zone____ State_____

DOW CORNING CORPORATION
MIDLAND, MICHIGAN

ATLANTA • CHICAGO • CLEVELAND • DALLAS • LOS ANGELES
NEW YORK • WASHINGTON, D. C.

MoO3

TECHNICAL MOLYBDENUM TRIOXIDE

The lowest cost raw material for the production of all Molybdenum compounds, including Molybdenum Orange, Molybdenum Vermilion, and Molybdated pigment colors.

Our development department will gladly take up with you any problems involving the application of Molybdenum.

MOLY

Climax Molybdenum Company

500 Fifth Avenue New York City

C-11

PEOPLE

(*Continued from page 61*)

Lloyd G. Alexander

Lyle F. Albright

Lloyd G. Alexander has been appointed chairman of the University of Oklahoma's school of chemical engineering, as reported in "C.E.P." last month, and Lyle F. Albright has joined that department as assistant professor. Dr. Alexander, who holds B.S. and Ph.D. degrees from Purdue University, was research assistant professor of chemical engineering at the University of Illinois for two years before he joined OU in 1950. Dr. Albright, who received his Ph.D. degree from the University of Michigan in 1950, was formerly in the research development department of Colgate-Palmolive-Peet Co., and will institute a study on oils and fats at Oklahoma University.

Norman T. Robey became an additional assistant general superintendent of the Casper (Wyo.) refinery of Standard Oil Company (Indiana) Dec. 1. He had been assistant superintendent of the heavy oils division at the company's Wood River (Ill.) refinery. Mr. Robey joined Standard in 1936 as a chemical engineer in the Whiting, Ind., research laboratory, where he became a group leader in 1941. Two years later he was transferred to the Wood River refinery as foreman of the catalytic cracking unit. He subsequently served at Wood River as general foreman of the cracking department, assistant superintendent of the light oils division, and supervisor of training in the industrial relations division.

Constantine L. Tsaros is a recent addition to the research staff of Standard Oil Company (Indiana) at Whiting, Ind. Mr. Tsaros received his B.S. in chemical engineering from Purdue and his master's degree from the University of Michigan. He was recently associated with the Institute of Gas Technology.

Arthur L. Gardner has announced his retirement from the Monsanto Chemical Co., Boston, Mass., with which he has been affiliated for a number of years. Mr. Gardner, who received his B.S. degree in chemical engineering from the Massachusetts Institute of Technology, was formerly associated with the Roessler & Hasslacher Chemical Co., Perth Amboy, N. J., and the New England Manufacturing Co., North Woburn, Mass.

J. H. Forrester has been appointed manager of research for the Standard Oil Co. (Indiana). He is currently manager of Standard's subsidiary, the Stanolind Oil and Gas Co., Tulsa, Okla. Mr. Forrester received his M.S. in chemical engineering at Massachusetts Institute of Technology in 1932 and has held various research positions with the Standard Oil Co. since 1929.

Gordon H. Lovett, recently transferred from the Monsanto Chemical Company's central research laboratories at Dayton, Ohio, has been appointed project leader in that company's plant at Texas City, Tex. Mr. Lovett attended Purdue University and joined Monsanto in 1946, after a three-year term with the Navy.

Necrology

N. G. BRADFORD

Nevin G. Bradford, district sales manager of the General Ceramics & Steatite Corp., Cleveland, Ohio, died Oct. 19, 1951, in an automobile accident. He was previously sales engineer with the same company in the East. Prior to 1949 Mr. Bradford served as plant superintendent with Flintkote Co., at Morristown and at East Rutherford, N. J. He graduated from Newark College of Engineering with a B.S. in chemical engineering in 1938. His professional specialties were the design of hydrochloric acid plants and techniques of emulsification.

WILLIAM M. BOOTH

William M. Booth, a consulting chemical engineer and member of A.I.Ch.E., died of a heart attack Oct. 22, at the age of 81. After receiving his M.S. degree in chemical engineering from Harvard University, he spent ten years as teacher and assistant in schools in New York, Connecticut and Massachusetts. Early in his career, he was identified with the Beach & Clarridge Corp., Boston, Mass., and the Wickwire Steel Co., Cortland, N. Y.

JOHN L. WALLACE

John L. Wallace, a chemical engineer for the Glidden Co., Cleveland, Ohio, and previously chief engineer with Master Chrome Service, Inc., in that city, died Oct. 16, 1951. Dr. Wallace received his B.S. degree from Polytechnic Institute of Brooklyn, his M.S. from Rensselaer Polytechnic Institute, and his degree as Doctor of chemical engineering from Yale University in 1939. Following his graduation from Yale, he was employed by the Du Pont Co., Wilmington, where two years later he became an industrial engineering group head.

INDEX OF ADVERTISERS

	Page
Aluminum Co. of America	11
American Instrument Co., Inc.	54
Atlas Mineral Products Co.	60
Babcock & Wilcox Tube Co.	15
Baker Perkins, Inc.	7
Barnstead Still & Sterilizer Co.	59
Bartlett & Snow Co., The C. O.	43
Buffalo Equipment Division	8
Carbide & Carbon Chemicals Co., A Division of Union Carbide and Carbon Corp.	16
Chicago Bridge & Iron Co.	58
Chikson Co.	36
Cleaver-Brooks Company	23
Climax Molybdenum Company	64
Cooper Alloy Foundry Co.	53
Corning Glass Works	45
Crane Company	26
Croll-Reynolds Company, Inc.	65
Darr Company	49
Dow Chemical Co.	29
Dow Corning Corp.	63
Fansteel Metallurgical Corp.	55
Fischer & Porter Co.	3
Fluor Corp., Ltd.	27
Foster Wheeler Corp.	9
Foxboro Co.	25
General American Transportation Corp., Inside Front Cover,	10
Glycerine Producers, Inc.	31
Great Lakes Carbon Corp.	6
Gump Co., B. F.	62
Hammel-Dahl Company	38
Hardinge Company, Inc.	44
Haynes Stellite Co., A Division of Union Carbide and Carbon Corp.	51
Hilliard Corp.	60
Infilco Inc.	14
Instruments, Inc.	56
Johns-Manville	47
Knight, Maurice A.	50
Lapp Insulator Co.	57
Lummus Company	30
Martindale Electric Co.	56
Minneapolis-Honeywell Regulator Co.	4, 5
National Carbon Co., A Division of Union Carbide and Carbon Corp.	35
Nicholson & Co., W. H.	60
Potter Aeronautical Co.	32
Pritchard & Co., J. F.	46
Proctor & Schwartz, Inc.	37
Read Standard Corp.	28
Republic Flow Meters Co.	12
Sparkler Manufacturing Co.	61
Spray Engineering Co.	65
Struthers Wells Corp.	13
Swartwout Company	33
Swenson Evaporator Co., Div. of Whiting Corp. Back Cover	
Thermal Syndicate, Ltd.	48
Turbo Mixer Div., General American Transportation Corp. Inside Front Cover	
U. S. Electrical Motors, Inc.	21, 22
U. S. Stoneware Co.	594
Union Carbide and Carbon Corp. Carbide and Carbon Chemicals Co.	16
Haynes Stellite Co.	51
National Carbon Co.	35
Vulcan Copper & Supply Co. Inside Back Cover	
Whiting Corp., Swenson Evaporator Div., Back Cover	

SPRACO NOZZLES

Write for NOZZLE CATALOG *to*

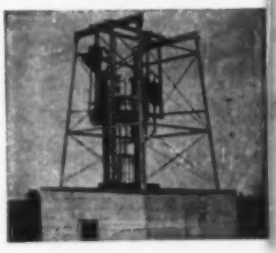
SPRAY ENGINEERING CO.

132 CENTRAL STREET • SOMERVILLE 45, MASS.

IS VACUUM

THAT'S 99.99% PERFECT

good enough for *your* process?



THIS degree of vacuum is easily obtained with the Croll-Reynolds four or five-stage steam jet EVACTOR with no moving parts. Each stage from a technical standpoint is as simple as the valve that turns it on. Numerous four-stage units are maintaining industrial vacuum down to 0.2 mm. and less, and many thousands of one, two and three-stage units are maintaining vacuum for intermediate industrial requirements on practically all types of processing equipment.

By permitting water, aqueous solutions or any volatile liquid to evaporate under high vacuum and without heat from an outside source, enough BTU's can be removed to chill the liquid down to 32° F., or even lower in the case of solutions. This is the principle of the Croll-Reynolds "Chill-Vactor." Hundreds of these have been installed throughout the United States and in several foreign countries.

An engineering staff of many years experience has specialized on this type of equipment and is at your service. Why not write today, outlining your vacuum problem?

CROLL-REYNOLDS CO., INC.

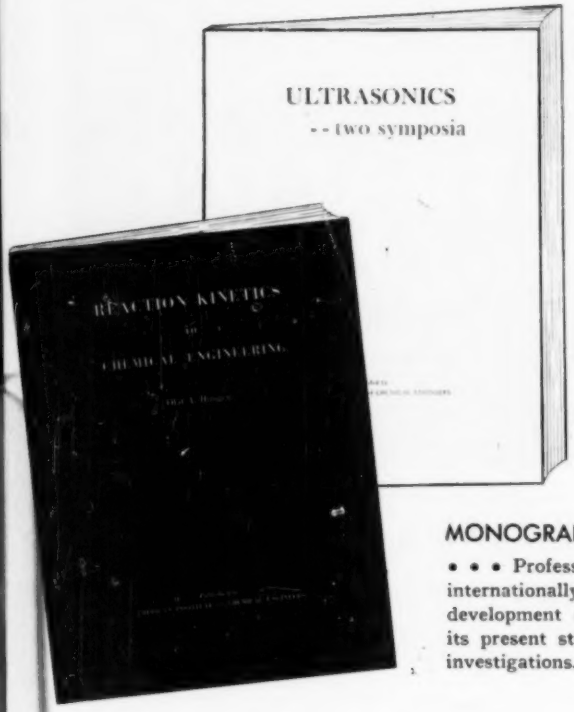
Main Office: 751 Central Avenue, Westfield, New Jersey

17 John Street, New York 38, N. Y.

Chill-Vactors Steam Jet Vactors Condensing Equipment

Chemical Engineering Progress

MONOGRAPH SERIES & SYMPOSIUM SERIES



SYMPOSIUM SERIES No. 1 ULTRASONICS

Dudley Thompson, *Symposium Chairman*

AUTHORS

J. W. Butterworth	J. L. Norton
B. Carlin	R. W. Samsel
Egon A. Hiedemann	Karl Sollner
J. C. Hubbard	C. A. Stokes
T. F. Hueter	J. E. Vivian
E. P. Neumann	Alfred Weissler

Abstracts of previously published papers by

Dudley Thompson, C. A. Stokes, W. H. Janssen

• • • studies in the uses and developments of ultrasonic energy—with discussion of its application to chemical engineering processes and operations.

MONOGRAPH SERIES No. 1 REACTION KINETICS

• • • Professor Hougen, of the University of Wisconsin and internationally known authority in the field, covers the historical development of chemical kinetics as applied to process design, its present status, and the most promising fields for immediate investigations.

• • • Publication of these series, under the auspices of the A.I.Ch.E., is an answer to the problem and the necessity of the hour—basic research knowledge at low cost for the chemical engineer. . . . Chemical Engineering Progress has been meeting this challenge but as new techniques and processes are being developed the demand for more knowledge multiplies. . . . Hence, the third publishing venture of A.I.Ch.E., the Monograph and Symposium Series, to bring you up to date on the recent findings in chemical engineering. . . .

MAIL THIS COUPON

CHEMICAL ENGINEERING PROGRESS
120 E. 41st St., New York 17, N. Y.

Please send

☐ Copies of Reaction Kinetics in Chemical Engineering
☐ Copies of Ultrasonics—two symposia
Check enclosed ☐ Please bill me ☐

Name_____

Address_____

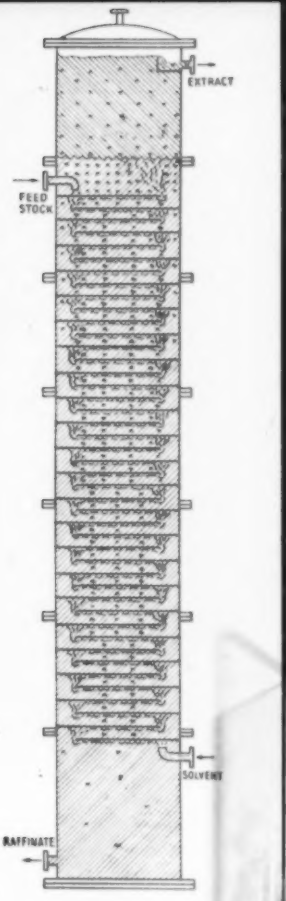
	PRICES	
	Members	Nonmembers
Reaction Kinetics	$2.25	$3.00
Ultrasonics	2.00	2.75
Both Volumes	4.00	5.50

(Paper covered)

Please check:

Junior Member ☐ Active Member ☐
Associate Member ☐ Student Member ☐
Nonmember ☐

☐ Enter my subscription on a yearly basis to receive future volumes as they are issued. I will be billed as the books are published.



Diagrammatic sketch of liquid-liquid extraction column.

SOLVENT EXTRACTION

The photo above shows a complete wood rosin purification plant designed and constructed by Vulcan, utilizing the Vulcan solvent extraction process.

THE Vulcan baffle-type liquid-liquid extractor consists of a vertical column packed with a series of horizontal baffles. The turbulent region at the edge of each baffle serves to remix the liquids between stages. Either phase may be the continuous phase. Each baffle is made horizontal and flat by the use of adjustable spacer posts.

This equipment has been highly successful in the organic chemical industry and it is equally suitable for hydrocarbon separations. Each new application is carefully checked in the Vulcan laboratories to assure economical design and to permit performance guarantees.

These extractors are available in all corrosion resistant materials and in diameters to ten feet.

The Vulcan organization is at your service to provide:

- Technical and [illegible] surveys
- Research and development
- Process and [illegible] design
- Equipment manufacture
- Plant erection and startup

50th Anniversary

1901 1951

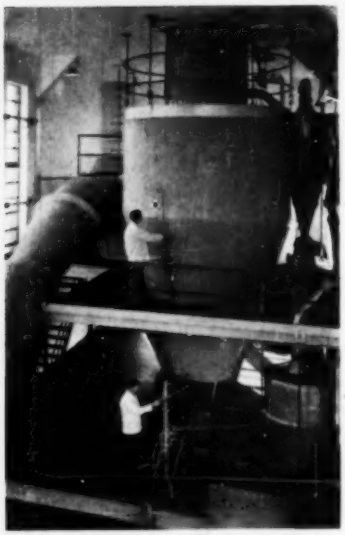
VULCAN • CINCINNATI

ENGINEERS AND MANUFACTURERS OF PROCESS PLANTS AND EQUIPMENT

The VULCAN COPPER & SUPPLY CO., General Offices and Plant, CINCINNATI 2, OHIO

PHILADELPHIA BOSTON SAN FRANCISCO BUENOS AIRES

TORRES VULCAN PROCESS MACHINERY CO., LTD., MONTREAL, CANADA



Above photos were taken inside the Swenson Spray Dryer Laboratory

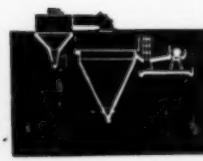
—then probably you can profit by

SPRAY DRYING

By test-drying a typical sample in the Swenson Spray Dryer Laboratory, it can quickly be determined whether or not your material is susceptible to spray drying. Such tests may be arranged at reasonable cost.

As the result of data secured during such test runs, our engineers determine the most efficient, economical design for building production equipment.

Swenson Spray Dryers are now at work on a wide variety of materials, many of which were unknown just a few years ago. If you are working with a new material, do not overlook the economies of spray drying in your process. Swenson engineers are glad to offer every possible co-operation.



SWENSON EVAPORATOR CO.
DIVISION OF WHITING CORPORATION
15690 Lathrop Avenue Harvey, Illinois
Eastern Sales Office and Export Department: 30 Church Street, New York 7, N. Y.
In Canada: Whiting Corporation (Canada) Ltd., 47-49 LeMoine Ave., Toronto 2